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K. Headlam-Morley

MANAGING EDITOR
E. R. Mort, B.Sc., F.I.M.

ASSISTANT EDITOR
C. R. Harman, B.Sc.(Eng.)

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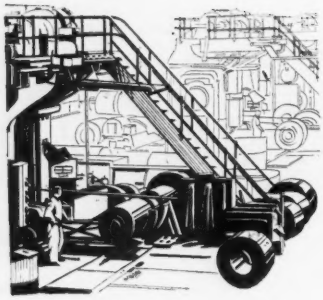
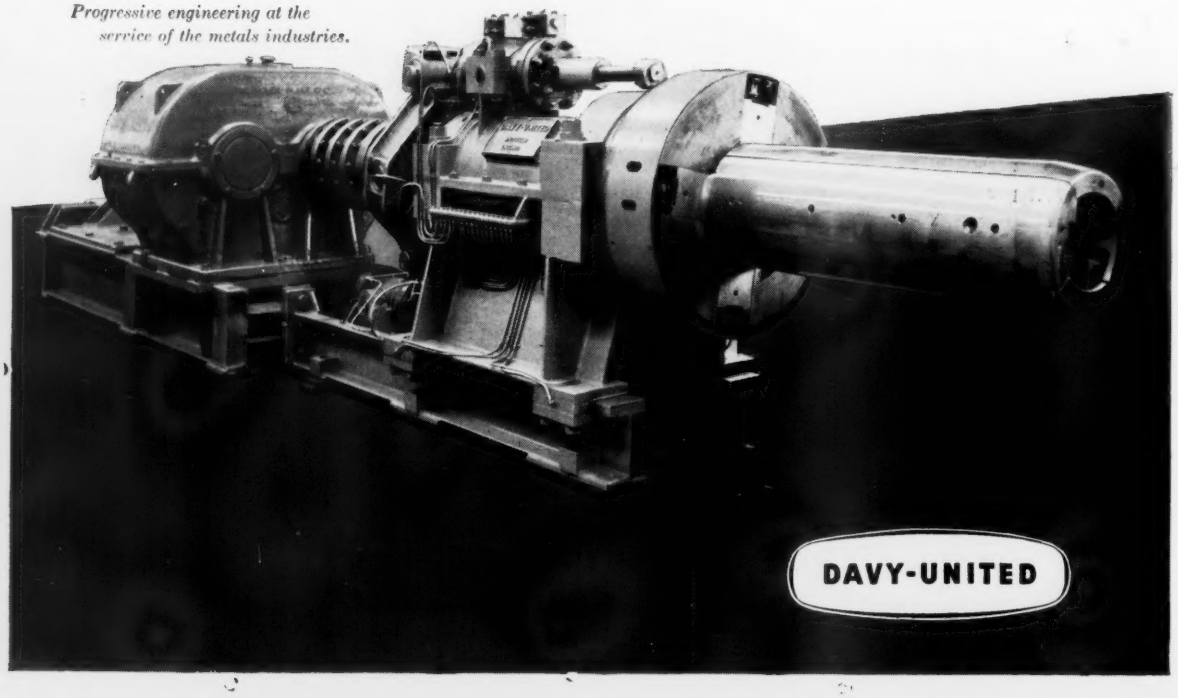


A PAY-OFF REEL OF NEW DESIGN

This new Pay-Off Reel is one of three specially built for the Tinplate Temper Mills in the Ebbw Vale plant of Richard Thomas & Baldwins Ltd. They are replacing existing cone-type uncoilers, with the express object of eliminating waste which can result from uncoiler cones damaging the inside wraps of the coiled strip.

Of a new design, and giving a larger collapse than has been used previously, this particular Pay-Off Reel is fitted with a drag generator, thus providing heavier and better controlled back tension than is possible with the cone-type uncoiler. It can deal with coils up to a maximum diameter of 51 inches, a width of 38 inches, and a weight of approximately 18,000 lbs.; special coil ejector gear can be fitted if required. Reels of this type can be built to handle the largest coils likely to be required.

Progressive engineering at the service of the metals industries.



A. H. INGEN HOUSZ

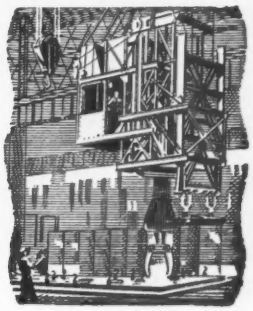
ARNOLD HUGO INGEN HOUSZ was born at the Hague. He received his technical education at the Technical University, Delft, where he obtained a degree in mechanical engineering in 1911. He took up his first appointment with the Royal Dutch Shell Concern and was sent out to Rumania and Russia. In 1914 he returned to the Netherlands and was appointed engineer of the Municipal Gasworks at the Hague. Thereafter he joined the contracting firm Hollandsche Beton Maatschappy, and in 1917 joined Mr. Wenckebach, the founder of the Ymuiden plant, in the preparations for the erection of these works, being his technical assistant during all the planning and the construction of the plant.

In 1924 Mr. Housz became a Managing Director of the Royal Netherlands Blast-Furnaces and Steelworks (Hoogovens) at Ymuiden, and was nominated President of the Board of Managing Directors in 1945. He is also President of the Board of Managing Directors of Breedband (wide strip mill and tinplate mill) and a member of the same Boards of Mekog (nitrogenous fertilizer plant) and Cemij (cement plant), all of them affiliated with Hoogovens.

Mr. Ingen Housz is prominent in Dutch industrial life. He is a member of the Board of the Federation of Netherlands industries, and figures on the Boards of various other Dutch companies. For many years he was on the Board of the Royal Institute of Engineers. He is Chairman of the Association of Netherlands Iron and Steel Producing Industries, and is a member of the Consultative Committee of the European Coal and Steel Community.

His special interests, next to the steel industry, are in the educational sphere. He is a Guardian of the Amsterdam University and a member of the Council of the Rotterdam School of Economics. He joined The Iron and Steel Institute in 1931, and was Chairman of the Reception Committee for the special meeting of the Institute held in the Netherlands in October, 1953. During the meeting it was announced that Mr. Housz had been nominated an Honorary Vice-President.

A. H. Ingen Housz
Honorary Vice-President



Soaking Pit Practice

AT THE NORMANBY PARK STEELWORKS OF JOHN LYSAGHT LTD.

By A. H. Norris

SYNOPSIS

This paper deals with the results of three years' experience of working a battery of one of the first post-war installations of one-way top-fired soaking pits. The results show how modern advances in instrumentation and construction have a considerable effect on heating efficiency, in regard to both heat consumption and quality of steel.

The comparatively recent tendency to use coke-breeze bottoms in soaking pits is dealt with fully. The results shown in this paper should prove useful for purposes of comparison and improvement in the many other more recent installations for which results have not yet been published. 805

Introduction

THE Normanby Park Steelworks of John Lysaght Ltd. have been virtually rebuilt during the last four years, the rolling mills and the soaking pit installation being completely new. Since September, 1952, the mills have been rolling 10–11 thousand tons per week comfortably in 16 shifts, and most of the data in this paper have been obtained during that time.

The mills consist of a 42-in. cogging reversing mill and a Morgan continuous billet mill, and were originally intended for the mass production of mild steels containing up to 0·30% of carbon. In practice, however, very large tonnages of steel with up to 0·60% of carbon are also rolled, including free-cutting steels, 0·5–4·5% Si steels, and many other special grades. This fact is mentioned because many of these steels require special treatment or long heating times, and this should be borne in mind when comparing the records of these soaking pits with other similar installations.

A melting shop of eight 120-ton fixed furnaces, one 180-ton tilting furnace, and two active mixers of 400 and 500 tons capacity respectively supplies steel for the mill at an average of 10,500 tons per week. Not more than eight furnaces are in operation at any one time. There are three teeming stations, each with an automatic ladle stand, and a fourth static stand fitted for the production of leaded steels.

Moulds to produce a 4-ton ingot are cleaned and made up in a separate mould-conditioning bay. Four moulds are mounted on bottom plates on each sprung bogie fitted with roller bearings, and the bogies are drawn by one Diesel locomotive, which deals adequately with all ingot traffic from the conditioning shop to the pit and from the pit, after weighing, to the stripper building.

The stripper bay, 250 ft. long with an 85-ft. span, is parallel to and adjacent to the pit side, the mould conditioning shop being on the other side of the stripper building. The stripper station has a balloon siding of four sets of rails, so that two casts can be withdrawn from the pit side and set for stripping. The balloon siding then feeds into a double track at the soakers, where the stripped casts can be set as required.

The two stripper cranes are each of 6 tons capacity and, since the soaking-pit building is a continuation of the stripper bay, can if necessary be used for charging ingots into the pits.

ARRANGEMENT OF SOAKING PITS

The soaking-pit bay, 320 ft. long with an 85-ft. span, is serviced by two 5-ton overhead charging and drawing cranes. A third 5-ton crane is provided in the lean-to at the rear of the pits over the operating platform and recuperators, for general handling purposes. The instrument panels and lid-opening controls are also situated on this platform. A special controller is fitted in the cabs of both the overhead cranes, so that the lids can be operated by the crane drivers as well as by the heater.

The soaking pit installation consists of 12 one-way top-fired pits in three batteries, each battery incorporating four cells (*see* Fig. 1). Each pit is 25 ft. long by 7 ft. 6 in. wide by 11 ft. 9 in. deep and accommodates 18 3½- to 4-ton ingots, so that the total overall capacity is about 800 tons for the three batteries. The pits were designed to use a coke-breeze bottom; details of this process are given on p. 355.

The pits are fired by a mixture of blast-furnace and coke-oven gas, the mixture having a calorific value of 135 B.Th.U./cu. ft. and the following composition: 9·70% CO_2, 27·89% CO, 2·37% CH_4, 0·28% CNH_2N, 7·55% H_2, 0·01% O_2, 52·20% N_2. The total air for combustion is preheated in refractory

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Mr. Norris is Rolling Mills Manager of John Lysaght Ltd.

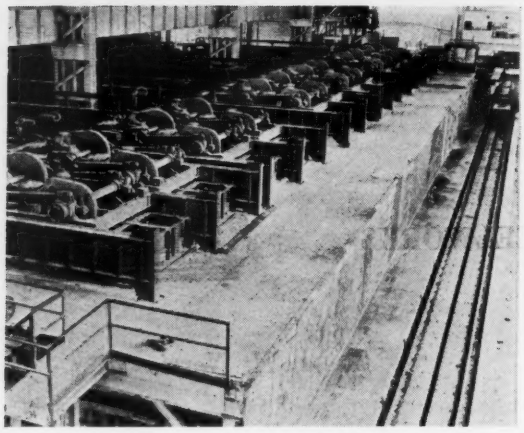

Fig. 1—Section of pits. Note the bogie track and clear view of cogging mill

recuperators built at the rear of the pits and is delivered to the burners by an electrically driven hot-air fan (suitable for temperatures up to 590° C.) which delivers air at 2½–3 in. W.G. A single burner of special circular design is built into the rear wall of each pit, the air being delivered to the centre of the burner and the gas through a ring-shaped space surrounding the air. Mixing of the gas and air occurs at the burner nozzle, and is arranged so that the correct type of combustion is produced above the ingots.

The recuperators consist of a double chamber for each battery of four pits, and are made up from a large number of recuperator blocks arranged for two-pass air flow and single-pass waste-products flow. The connections between the recuperators and the fans and burners are of mild steel lined with insulating brick, with asbestos-board backing. The outlet port for the waste gases is immediately below the burner, so that the flow of the products of combustion through the pits is of a vertical horse-shoe form. A firebrick-lined steel chimney, 150 ft. high and 6 ft. dia., is provided for each battery. Between the recuperators and the chimneys are hand-operated dampers to ensure uniform pressure conditions in the recuperators' flue system.

The pits can be either automatically controlled (with provision for setting the temperature, pit pressure, and gas/air ratio as required) or operated manually. Gas pressures and the proportions of blast-furnace and coke-oven gas are controlled by a mixing station, and gas-pressure and gas-consumption recorders are provided. Each pit is controlled individually by (i) an air-operated temperature-recording control for operating the main gas valve to each pit, (ii) a combustion control which regulates air flow in accordance with the gas and maintains a correct air/gas ratio, and (iii) a pit-pressure control which operates the individual damper at the waste-gas outlet from each pit. A total-gas-flow meter is provided for each pit, and the air flow and pit pressure are recorded by special equipment.

The pits are covered with refractory-lined lids fitted with lifting and travelling mechanisms operated by separate motors. The gas is automatically shut off as the lid is opened. Seal troughs are provided around the tops of the pits, with clipper castings on the lids so that the pits are completely sealed, enabling them to be operated at a pressure slightly above atmospheric. For inspection purposes the lids, after being lifted out of the seals, can be travelled forward and backward when charging or drawing ingots (*see* Fig. 2).

The ingots are delivered from the pits on to an ingot bogie capable of carrying 40 ingots/hr. up to the cogging mill. Those ingots that have to be entered bottom end first into the rolls can either be carried by the cranes direct to the entry table or be placed on steel slabs let into the brickwork in front of each pit, before being reversed into the bogie.

Brickwork

The brickwork in the pits has stood up very well to three years of operation, although some modifications have been necessary to improve the pit efficiency.

In the first few weeks the ingots were often heated to too high a temperature, and many were left in the pits much too long. This was due partly to faulty reading instruments, but mainly to the fact that the operators in the new cogging mill were naturally slow so that, to enable the blooms to reach the Morgan mill at a reasonable entering temperature, the ingots had to be deliberately overheated. Also, breakdowns in the mills gave rise to bad conditions at the soaking pits, resulting in damage to the floor and bottom side bricks.

Since those early days it has been necessary to renew the pit floor bricks once a year; this applies also to the bricks in the breeze vent, which receive a certain amount of ill-treatment from the ' poker ' (*see* p. 355).

The side walls were originally fitted at the bottom few courses with chrome bricks, but these have been found to be quite unnecessary and ordinary firebricks are now used. The latter appear to need renewal every two years.

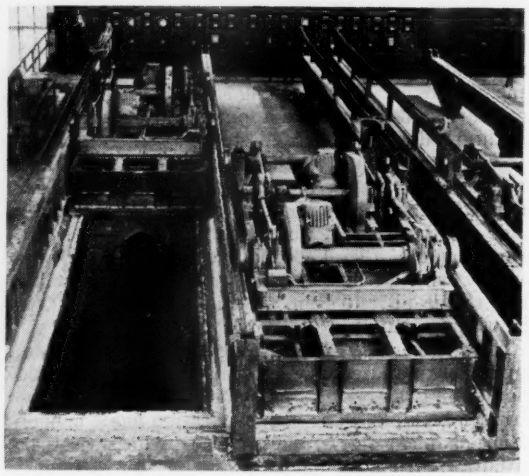

Fig. 2—Section of pit showing lid retracted. Note burner above exit flue, and the upright position of ingots on each side of the pit

Trouble was seldom experienced with inside walls, but the outside walls were inclined to ' bow ' slightly. This was caused partly by the use of sand in the seals originally and partly by the tendency of the locking lugs in the seal bricks in the wall tops to break. For some time, therefore, grit has been used instead of sand in the seals, with the result that the original wall-leaning tendency has decreased; also, the seals now very rarely have to be refilled, whereas formerly this was constantly necessary.

A certain amount of gas used to leak through the brickwork above the burner opening and was often most unpleasant for the operators. Accordingly, a steel cylinder was welded on to the burner and the bricks were then built round the cylinder; this completely stopped the leakage, as the gas was forced directly from the burner through the cylinder into the pit.

No trouble has been experienced with any other brickwork, and there is no apparent wear in the checkers.

In the types of pit formerly used by this Company, frequent repairs to the lid brickwork were necessary. After three years working with the present installation, only six small patches have been put in and four lids have had to be fettled. No complete rebuild has yet been necessary, although a recent close examination of the lids showed that they will all need rebuilding during the next twelve months. This will give an estimated brick life of 3–4 years.

The ingots are stood upright in the pits, and little damage has been done to the walls by the crane drivers. Sometimes, however, bought ingots which have to lean against the walls are introduced, with subsequent slight damage.

Breeze Bottoms

After careful consideration it was decided to use coke-breeze bottoms on the pits. Experience has proved that this was a wise policy, and the Company is very satisfied with the results.

The breeze is discharged into a 20-ton capacity bunker, which in turn discharges into 30-cwt. breeze skips. An additional brick bunker has been built to accommodate a further 100 tons.

Four skips are emptied into each pit bottom—a total of 6 tons, giving an initial breeze height of 18 in. The piles of breeze are then levelled by a rake gripped by the overhead crane dogs, the operation taking 20 min. to complete. The gas is then put on, and the breeze is burnt-in at a pit temperature of 1200° C. for 1½ hr. This is the most important part of the operation. Failure to burn-in the breeze, or attempts to cut down the burning-in time, would result in cold ingot bottoms and the removal of large quantities of breeze with the ingots after the initial charge. Manipulation troubles would be experienced in the cogging mill, and any time initially saved by charging too early would ultimately be lost in reduction of output.

When cleaning the pits, a pan is placed under each of the two vents in the pit bottom (*see* Fig. 3). The vents are opened by a mechanical device, and the scraper, gripped by the crane dogs, sweeps the used breeze into the pans below. It is often necessary to push a poker tool, also gripped by the crane, through

Fig. 3—Waste coke-breeze cars under vents in pits

the vents. In the early days the vents became badly choked with slag and were damaged when the poker was forced through. Nowadays the vents seldom seize up, and if they do, oxygen lances used from below are quite effective in clearing a small hole, leaving the poker to do the rest.

The well of the pits is fitted with two parallel track lines and turntables, and the pit-bottom men have no difficulty in wheeling the pans with their loads to the north end of the installation, where a crane picks up the pans and tips the contents into a slag ladle. Rails have now been laid parallel to and beneath the bogie track, so that scale can be thrown into pans during the week-ends and carried away on the same rail system that operates under the pits.

Cleaning a pit normally takes only 10 min., so that the whole operation of breezing takes 2 hr.

Breeze ½ in. and less is preferred, and there is no objection to using dust. Many types of breeze were experimented with in the old soaking-pit installation, but any breeze with an ash fusion point of below 1320° C. has been found to be useless. The breeze normally used has an ash fusion point of 1360–1380° C. or even higher.

Careful records are kept of breeze consumption. During 1952 each pit averaged 10·81 working days between being cleaned and breezed. These figures are based only on the days when the pits were under gas and contained ingots; naturally, days when the pits were off for repairs or idle for lack of steel were not included. The pits have gone for longer periods between cleanings and no doubt could, on the average, go to 12–14 working days, but no chances are taken in this respect.

During 1952 an average amount of 177·57 tons of steel per pit was heated for every ton of breeze used, but in the last quarter of that year the average jumped to well over 200 tons as the outputs increased.

Experiments were carried out to see whether the pits could be cleaned less frequently and breezed more often. The present policy was found to be more satisfactory, and during 1952 extra breeze was added only between cleanings, once to each pit every two

months. Usually, this extra breezing is carried out only when a soaking-pit crane is under repair for a long period during the week—just to keep the pit in commission until the crane is available again to clean the bottom.

Where normal heating practice is carried out, virtually no slag ever forms on the ingot bottoms. When there is a major mill delay and the pits contain carbon and mild steels only, there is very little trouble provided that the pits are eased down. High-silicon steels, however, present a different problem. It is necessary to manufacture and roll well over 1000 tons of 4% Si steels at the beginning of each week. Twice during 1952, major delays took place on the first shift of the week, and nearly all the pits contained high-silicon grades. Temperatures were reduced to 1100° C., but all the pits had to be cleaned out as soon as possible, as slag had formed on the bottoms. Luckily, this condition is most abnormal and the coke-breeze bottoms give every satisfaction.

OPERATING DETAILS

The pits are gassed at 10.0 a.m. each Sunday, charging usually commencing at the same time and continuing up to 10.0 p.m., when the mills start rolling. There are 16 production shifts, and gas is cut off and the pits are closed down at 6.0 a.m. on Saturdays. This number of shifts is necessary to roll 11,000 ingot tons, the size of the bloom on most orders varying between 25 and 36 sq. in. The main bloom sizes are 12½ in. × 2 in., 5½ in. × 5½ in., and 6 in. × 6 in. If the number of rolling shifts is increased to the normal 17, it is reasonable to suppose that on existing bloom sizes the mills could roll 11,500–12,000 tons weekly. Since the mill went into operation the percentage of cold steel charged has been as high as 50% per week, but the average figure is 25% and it has never dropped below 20% in any one week.

When 11,000 tons are rolled all 12 cells are used, but on lower weekly outputs two cells are always closed down as soon as the cold steel has been charged.

The drawback, from the standpoint of repair, is the extremely slow rate of cooling the pits when the gas is shut off, as the breeze bottoms retain the heat for days. The advantages, however, far outweigh this disadvantage: slow cooling keeps the brickwork in good trim, and, as the checkers retain the heat so well, the pits reach suitable charging temperatures very quickly.

The hot-air temperature control for each battery is set at 540° C., although it is set somewhat lower for the middle battery. The waste gases enter the recuperators at temperatures of 900–1000° C. and leave them at 400–450° C.

For most steels the recorders are set at 1250° C.; for high-silicon grades they are set at 1230° C., and for free-cutting qualities at 1270° C. When drawing, there is a fall of 100–150° C. in the recorder temperature. The temperature of the blooms leaving the cogging mill is 100–120° C. less than the recorded pit temperature at commencement of drawing, and this gives a bloom temperature of 1120–1150° C. The temperature of the bloom entering the continuous billet mill, always recorded, varies mainly between 950° and 1050° C.

The management insist that each heat must have a soaking period of at least 1 hr. If a shorter period were allowed, the last few ingots drawn would be appreciably colder than the first, with consequent ill effects in quality and on rolling speeds.

Each cast is of 120 tons and consists of 30–32 ingots, which are split between two cells. Eighteen cold ingots are always charged, as this number has been found to give the best results.

Hot steel is ready for rolling 3–4 hr. after charging, and sometimes sooner. Cold steel—a 70-ton charge—normally takes 10–12 hr. All ingots are stood upright where possible.

Nearly all heats are brought to temperature on automatic working; but on very special qualities, where very slow heating is necessary, manual control is exercised usually up to 1000° C., after which automatic heating is used.

Table 1

GAS SAMPLING IN No. 1 SOAKING PIT WITH ORIGINAL BURNER

Mixed-gas ratio: 10 parts blast-furnace gas to 1 part coke-oven gas
Mixed-gas pressure: 4 in. W.G.
Combustion regulator: 0·83
Pit pressure: 0·05 in. W.G.

Temperature, °C.	Mixed Gas, cu. ft./hr.	Hot Air, cu. ft./hr.	Position*	Composition			
				CO_2, %	O_2, %	CO, %	Excess Air, %
1200	105,000	117,000	S.T.	19·5	0·6	3·5	2·8
			S.B.	18·6	3·2	Nil	15·4
			E.	18·9	3·3	Nil	15·7
1240	107,000	120,000	S.T.	20·2	0·4	3·2	1·9
			S.B.	18·9	3·1	Nil	14·8
			E.				
1250	41,000	44,000	S.T.	18·8	0·5	4·4	2·4
			S.B.	17·9	2·3	Nil	11·0
			E.	17·0	4·0	Nil	19·0

* S.T. = side top; S.B. = side bottom; E. = end

True oxidation losses are most difficult to assess. Tests taken on cold ingots where all ' fash ' and scabs were missing and the tops and bottoms were solid have shown losses as low as 0·8% and as high as 2%. (In the latter case, special quality ingots kept up to 18 hr. in the pits were used.) From a number of other tests on clean solid ingots heated from cold, the results varied between 1·0% and 1·5%.

EXPERIMENTS

Extensive experiments have been carried out to discover what actually takes place in the pits during heating. Pit No. 1 was selected for test purposes, holes being drilled in the outside wall for the introduction of the necessary equipment. The metering system installed is calibrated for mixed gas.

Gas sampling was carried out on various heats over a period of weeks; a typical recording has been selected and is shown in Table I. Although the general results and performance of the pit were quite good, examination of the figures showed considerable room for improvement. Firstly, the excess air in various parts of the pit varied considerably and uniformly good combustion was not taking place, and secondly, control at soaking temperatures was by no means satisfactory.

From the data obtained, two vital alterations to this pit were made and put into operation: (i) By the introduction of new orifice plates the maximum mixed-gas flow was reduced from the previous maximum, and the meters were scaled down from a gas flow of 140,000 to 110,000 cu. ft./hr. The object of this was to give a greater differential pressure for the meters at low flows, thus giving an improved control of the pit atmosphere at soaking temperatures. (ii) An adjustable cone was introduced through the centre of the burner so that the air, instead of coming through the whole of the centre piece, would be forced into close proximity with the gas from the moment they both entered the pit.

Further tests were made with the new installations, and a typical sampling is given in Table II. The samples were taken with the baffle set as far back as possible in the burner; they refer to a charge of hot ingots at three stages of heating in the soaking pits.

The results exceeded expectations, and after three months' trial it was decided to equip all the pits in the same way. The whole installation was fitted with these modifications by the middle of 1953, and it was found by experiment that the extreme rear position for the adjustable cone was best. Since the insertion of this baffle, combustion and mixing have improved, and as the flue samples give a consistently good waste-gas analysis the gas and air proportions must be correct. Doubts were expressed that the burner alteration might cast the gas upwards and so damage the lid bricks, but there has been no evidence of this whatsoever.

In the following section, figures for pit No. 8 were selected at random to represent the initial burner equipment and higher gas flow, and figures for pit No. 1 to show the cut-down gas flow and the cone-shaped baffle installation in the burner.

OPERATION AND FUEL CONSUMPTION DATA

For these figures, track time has been taken as the time from tapping to finish of charging. The overall heat-consumption figures are taken from finish of charging to finish of drawing, except where charge-to-ready figures are given for No. 1 and No. 8 pits. The ingots are said to be ready for rolling 1 hr. after the gas flow has dropped to its minimum flow and remained constant.

Table II

GAS SAMPLING IN No. 1 SOAKING PIT WITH NEW BURNER

Mixed-gas ratio: 10 parts blast-furnace gas to 1 part coke-oven gas
Mixed-gas pressure: 3½ in. W.G.
Combustion regulator: 1·0
Pit pressure: 0·05 in. W.G.

Temperature, °C.	Mixed Gas, cu. ft./hr.	Hot Air, cu. ft./hr.	Position*	Composition			
				CO_2, %	O_2, %	CO, %	Excess Air, %
1220	102,000	128,000	S.T.	20·9	0·9	0·6	4·3
			B.B.	20·7	1·6	Nil	7·6
			E.	19·7	2·2	Nil	10·1
			F.	20·6	1·5	Nil	7·1
1245	62,000	81,000	S.T.	20·4	0·8	0·7	3·8
			B.B.	21·0	1·4	Nil	6·7
			E.	19·6	2·2	Nil	10·5
			F.	19·7	2·3	Nil	10·9
1255	30,000	37,000	S.T.	21·2	0·5	0·3	2·4
			B.B.	20·9	1·6	Nil	7·6
			E.	19·3	1·7	Nil	8·1
			F.	21·2	0·5	Nil	2·4

* S.T. = side top (level with top of ingot)
B.B. = back of pit taken from side wall (level with bottom half of ingot)
E. = front end of pit (level with bottom half of ingot)
F. = flue sample (snap sample)

} Samples taken over 15-min. periods

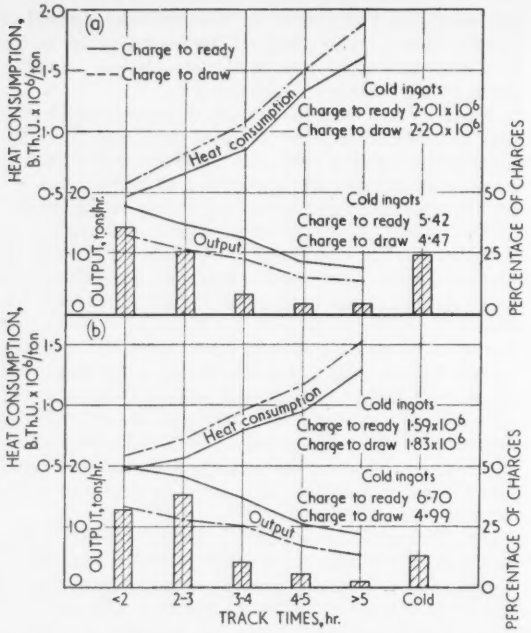

Fig. 4—Operating results compared with track times: (a) No. 8 pit with original burner; (b) No. 1 pit with new burner

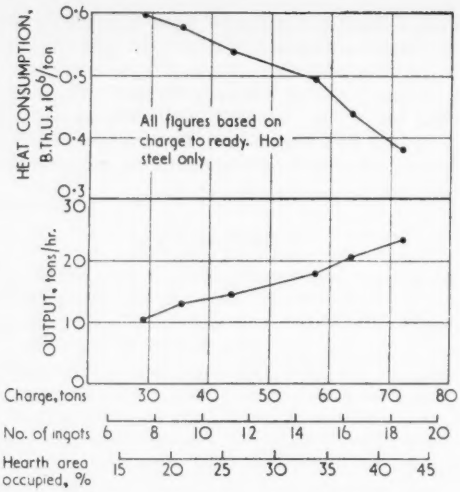
HEAT CONSUMPTION, B.Th.U. x 10⁶/ton
All figures based on charge to ready. Hot steel only
OUTPUT, tons/hr.
Charge, tons
No. of ingots
Hearth area occupied, %

Fig. 5—Operating results compared with charged weight

In 1951, the first full year of working on greatly reduced outputs, the charge-to-draw figures were 1,500,000 B.Th.U. per ton of steel. During the first six months of 1952 the figures were 1,276,000 B.Th.U./ton, including 25·7% of cold steel. During the second half of 1952, with the outputs increasing and 24·0% of cold steel, the consumption was 1,166,000 B.Th.U./ton. In the first quarter of 1953, with most pits running on a reduced gas flow, the figures fell to 1,100,000 B.Th.U./ton, and at the time of writing this paper the figures for the previous week were 1,020,000 B.Th.U./ton, with 30% of cold steel.

The best individual pit figures up to the end of March, 1953, taking charge-to-draw figures, were: 975,000 B.Th.U./ton with 29% of cold steel, 773,000 B.Th U./ton with 15% of cold steel, and 682,000 B.Th.U./ton with only 5% of cold steel. For the whole installation, therefore, it is not claiming too much to say that from charge to draw the figures are about 10 therms/ton with 25% of cold steel. These figures are based on a 16-shift week with a throughput of 10,500–11,000 tons.

When comparing the figures on No. 1 and No. 8 pits (*see* Fig. 4), the difference in operation is certainly quite marked. On very hot steel, however, there is little difference in heat consumption, although on black-hot and particularly on cold steel there is a very marked difference.

It may be of interest that for No. 1 pit the heat consumption on individual heats (hot steel) has been as low as 250,000 B.Th.U./ton with a heating rate of 30 tons/hr. On cold steel the best performance from charge to ready is 1,374,000 B.Th.U./ton with a heating rate of 8 tons/hr., but usually a fairly constant average of 15 therms/ton is maintained.

Amount of Charge

In the past, and on pits without modern instrumentation, it has always been a matter of opinion as to how many ingots should be charged to give the best results both in heating speeds (measured in tons/hr.) and in fuel consumption. This intriguing problem was tackled recently in these pits, hot steel only being selected, with track times not exceeding 2½ hr.

As already mentioned, a cast comprises 30–32 ingots, and hot casts are always split so that each cell accommodates 15–16 ingots, giving a tonnage of 55–65 tons depending on the quality. For these experiments data were collected from charges containing 8, 10, 12, 14, 16, and 18 ingots.

The results (Fig. 5) are as expected. The most interesting feature, however, is that at 18 ingots the heat consumption is still falling and the heating speeds are still rising, both fairly rapidly. It speaks well for the performance of these pits that the figures are still showing improvement when over 40% of the hearth area is being occupied.

With the present size of ingots, 20 cannot be accommodated, otherwise the experiment would have been

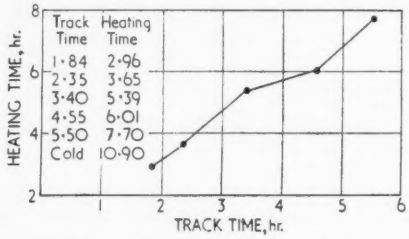

Fig. 6—Relationship between heating times and track times (heating time taken as charge to ready)

extended. This Company, however, is now experimenting with a square ingot, and it is possible that two more ingots of this type can be charged.

Finally, the relationship between heating times and track times is shown in Fig. 6.

Acknowledgments

The author desires to express his thanks to Messrs. John Lysaght (Scunthorpe Works) Ltd., and to the Managing Director, Mr. W. L. James, for permission to publish this paper and for his personal encouragement.

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Letter to the Editor

Method of Measuring Flame Radiation and Emissivity Continuously in Open-Hearth Furnaces

The effects of variables such as steam/oil ratio, fuel type and rates, and combustion-air/fuel ratios on the kind of flame in an open-hearth furnace, and hence their possible effect on output, are best studied by knowing continuously the flame radiation, emissivity, and temperature.

The use of the Schmidt method for measuring flame temperature and emissivity has been reported by the Flame Radiation Research Committee. The method was modified for use in the experimental furnace at Ymuiden, when it was shown that the radiation from the furnace walls backing the flame could provide the background energy to satisfy the following equations:

$R_1 = \sigma\epsilon_f T_f^4$
(Energy of flame alone)

$R_2 = \sigma\epsilon_f T_f^4 + (1 - \alpha_f)\sigma\epsilon_b T_b^4$
(Energy of flame alone + energy of background not absorbed by the flame)

$R_3 = \sigma\epsilon_b T_b^4$
(Energy of background at temperature T_b).

Experiments have shown that it is safe to assume that α_f (the absorption) is numerically equal to ε_f (the emissivity of flame) and that this value is independent of the temperature of the background radiation, so that it is possible to write:

$$\epsilon_f = \frac{R_1 - R_2 + R_3}{R_3} \text{ and } T_f = \sqrt[4]{\frac{R_1}{\sigma\epsilon_f}}$$

It has also been shown that the radiation from the furnace walls is equivalent to the black-body radiation emitted at the temperature of the surface of the bricks, so that it is possible to write $\varepsilon_b = 1$; this temperature is measured by a sheathed thermocouple placed so that the tip of the sheath projects a little way into the furnace chamber. The values of R_1 and R_2 were measured at Ymuiden with a narrow-angle mirror pyrometer focusing on to the hole in a diaphragm covering the junctions of a thermopile, which is set at an angle to the optical axis. Slots are provided on both sides of the furnace and opposite each other so that the pyrometer can be sighted straight through the flame on to a cold background to give R_1 and, by turning it through a small horizontal angle, through the flame on to the furnace wall to give R_2.

When this method was applied to an open-hearth furnace two difficulties arose:

(i) Continuous measurement of R_1 and R_2 was not possible, since the method involved physical manipulation of the pyrometer under conditions so arduous that a whole heat provided only very few readings.

(ii) It was impossible to measure continuously true surface temperatures of the inside wall of the furnace because the refractory wears back, leaving the sheathed thermocouple too far exposed, and at these high temperatures the Pt/Pt–Rh thermocouple becomes contaminated very rapidly.

The first of these difficulties has been overcome in the following way. The diaphragm covering the thermopile now has two holes side by side and the group of junctions of the thermopile opposite each hole are now connected separately to one point of a multi-point recorder. The energy received on one hole is made to come from the flame with a cold background behind it (R_1) and the energy on the other hole comes from the flame with the hot background (R_2). Thus no movement of the pyrometer need be made, since the same mirror focuses both streams of energy on to different parts of the thermopile, which is split according to the optical geometry involved. This could only be done with an off-axis arrangement of mirror and thermopile.

To solve the second problem, the following has been investigated. A hole approx. 12 in. × 6 in. was provided in the front wall of the furnace opposite the pyrometer sighted through the back wall and in line with the central axis of the flame. Half the area of this hole was blocked by a specially insulated sillimanite brick, in which a sheathed thermocouple was inserted so that its surface temperature could be measured. Care was taken with the thermocouple assembly so that there was minimum heat loss from the junction. The brick was pushed in so that a surface temperature of about 1500° C. (which is quite sufficient to give good accuracy to measurements of emissivities, which vary from about 0·25 to 0·85) was recorded. The other half of the hole was left open, so that the pyrometer measured the 'flame alone' value (it has been shown that a single water-cooled plate which might be used to block up the hole does not provide a non-reflecting background and therefore must on no account be used). Such a system has been installed and behaved very well for three days continuously, and there is every reason to believe that it solves the problem.

With these two improvements continuous measurement of flame radiation in open-hearth furnaces becomes a reality; the method can be extended to several points down the length of the flame, and even to measurement of the waste-gas temperature in the downtakes above stage level without using suction pyrometers.

R. Mayorcas
D. Thomas

Steelmaking Division,
British Iron and Steel Research Association,
Hoyle Street,
Sheffield, 3

Measurement of Air Flow Through the Strand in Sinter Plants

By F. Jordan and M. P. Newby

THE rate of air flow through the sinter bed along a continuous strand is a very important indication of the rate* of sintering. Such a measurement may be obtained from the pressure differential produced either by a standard Venturi or by a weir placed in the windleg. A series of calibrations has recently been carried out to enable the flow of air through the sinter-plant windlegs to be measured in this manner.

The Venturis were of the standard type, but they had to be calibrated, because they did not comply with the standard conditions of installation. The weirs were plates projecting from one side of the rectangular windlegs, and two different designs used in recently constructed plants are shown in Fig. 1.

* E. W. Voice, S. H. Brooks, W. Davies, and B. L. Robertson, *J. Iron Steel Inst.*, 1953, vol. 175, pp. 97–152. R. F. Jennings, E. W. Voice, P. K. Gledhill, G. C. Carter, and C. F. Ely, *Ibid.*, 1953, vol. 175, pp. 267–277.

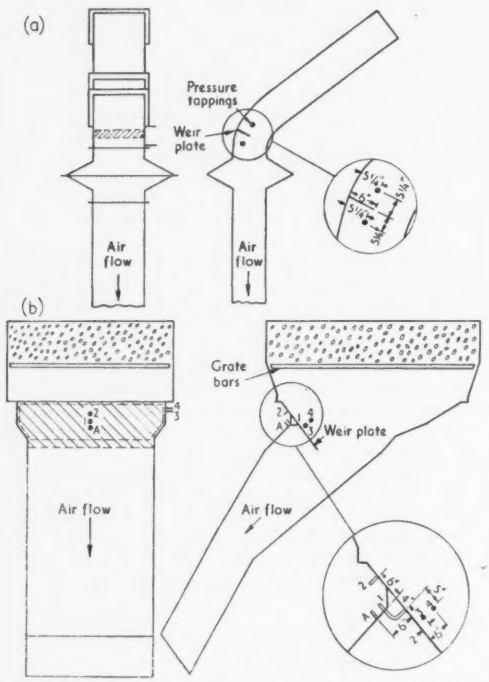

Fig. 1—Designs of weir for air-flow measurement

Pressure tappings are inserted in the windlegs upstream and downstream of the weir plates.

The weirs and Venturis were calibrated by building quarter-scale models and passing air through them in series with a standard orifice meter.

The relation between flowrate and pressure differential is given by an equation of the form

$$Q = CA\sqrt{p},$$

where Q is the volume flowrate of air, A is the cross-sectional area of the duct at the measuring part, p is the pressure differential, and C is a dimensionless coefficient which depends on the Reynolds' number. The air flow is generally in a fully turbulent condition at Reynolds' numbers of between 100,000 and 500,000. Under these conditions the coefficient C for a given installation is very nearly constant over the whole range of Reynolds' numbers. Since C is dimensionless it is sufficient to determine this constant value of C from the model and use it directly on the full-scale plant.

The relations between Q (cu. ft./sec.) and p (in. W.G.) are shown for the two full-scale weirs in Fig. 2. In Fig. 2*b* several results are given, corresponding to various positions of the pressure tappings. In general, tapping A_2 is to be preferred, as this gives the largest pressure differential for a given flowrate.

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Mr. Jordan and Mr. Newby are with the B.I.S.R.A. Physics Department.

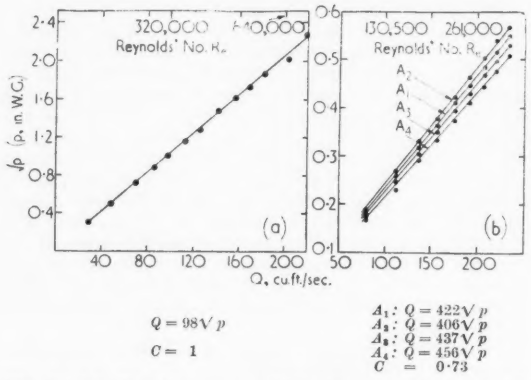

Fig. 2—Air-flow/pressure relation for weir shown in (*a*) Fig. 1*a*, (*b*) Fig. 1*b*

Propagation of Brittle Fracture in Steel

By T. S. Robertson, M.Sc. (Eng.)

SYNOPSIS

In notched-bar tests the material through which the crack propagates during fracture has suffered previous yield. The shape of notched-bar transition temperature curves is accounted for in terms of the effect of yield on the brittleness of the material.

In catastrophic failure, plates do not suffer the degree of yield which is applied in notched-bar tests. This paper describes the development of a new test which applies a known transverse stress and assesses the material through its ability to arrest a running crack. Test results for 29 plates in four qualities of mild steel are discussed. The effect of plate thickness is investigated. A comparison is made between the results of the new test and those of notched-bar tests on the same plates. 797

Introduction

In the history of the development of tests to reveal brittleness in materials, singularly little is recorded of any attempts to correlate such tests with the actual fractures that took place in practice. The Izod test became popular during the 1914–18 war because it showed up temper-brittleness in steel, but its inventor expressed surprise on more than one occasion that technical attributes should be credited to the test. Experimenters, however, began to investigate brittleness in terms of the test and soon established many effects. There was a speed effect, a notch sharpness effect, a size effect. The geometry of the test piece was overhauled and this resulted in a standard and a sub-standard test piece with a notch sharpness determined by the consistency or lack of scatter in results. In only very few cases of brittle fracture in practice could the test be said to simulate the actual conditions. This lack of real correlation led to great confusion when another variable, the temperature of test, was found to be all-important. With this variable added to even only the other three previously mentioned, the subject has so many facets that it would be indeed fortunate if those effects introduced by the test itself could be so controlled that the results would indicate what would happen to the steel in practice.

With the advent of large-scale brittle fracture in structures, the greatly increased research effort has resulted in departure by many experimenters from the standard tests, but almost all have this one feature in common: a notched bar is pulled or bent until a fracture starts from the vicinity of the notch. By observing some physical feature of the test or of the broken test piece the materials tested are put into an order of merit. That many of the tests put the materials into the same order of merit is but an indication that these tests subject the materials to the same type of action, and certainly it is not a proof that any of the tests produces the same action that results in brittle fracture in practice. It has been shown* that the very sharp notch produced by a fatigue crack put three steels in an order of merit different from that shown by notch tensile tests when a standard notch was used. There was also a loss of strength, not usually, though sometimes, reported in notched bar tests, and shown in this case to be present in all three steels when fatigue-cracked and also in 2-in. test pieces with standard notches (*see* Fig. 1).

This fall in strength with a standard notch took place while there was still appreciable general yield before fracture, and it is significant that, at temperatures below that for minimum strength, the brittle strength rises while the energy to fracture continues to fall, indicating a rapid decrease in the amount of yield before fracture. There remained a doubt as to whether the drop in strength was due to the action of fatigue on the material. To resolve this doubt two test pieces from the 2-in. material were fatigue-stressed in direct pull and push in a Losenhausen machine for 90% of their fatigue life of 250,000 cycles. The test pieces then had standard notches cut in them and were tested as notched tensiles at 20° C. The maximum stress recorded was still 40 tons/sq. in. The whole volume of the material had been subjected to fatigue damage at the same stress, whereas in the original tests the stress value fell off from a maximum at the notch to zero at the neutral axis of bending. It is considered that the test described above establishes that the loss of strength is attributable to the sharpness of the notch.

That yield took place at the root of the notch before propagation of fracture, even in the fatigue-cracked test pieces, had already been shown.* It therefore appears that local yield is necessary in static tests before propagation of brittle fracture from any notch, however sharp, existing before the test. With standard notches the degree of yield necessary before fracture propagates is much greater than with sharp fatigue cracks.

The work of Lea† shows that the effect of overstrain on the notch brittleness of mild steel increases with

* *Engineering*, 1951, vol. 172, Oct. 5, p. 444.

† F. C. Lea, *Proc. Inst. Mech. Eng.*, 1935, vol. 131, p. 539.

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Mr. Robertson is at the Naval Construction Research Establishment, Dunfermline.

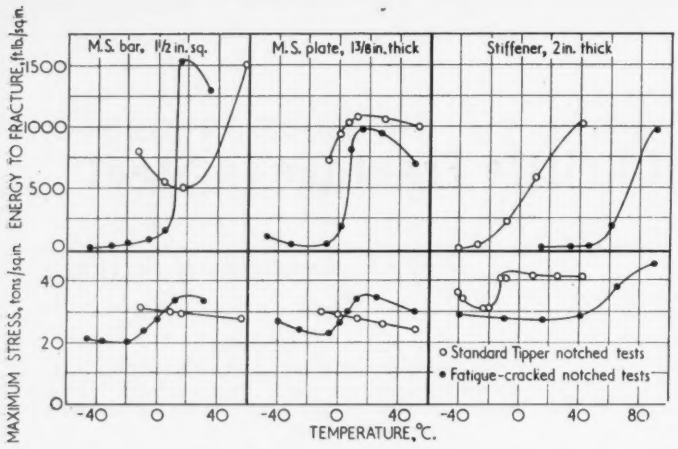


Fig. 1—Tipper and fatigue-cracked notched tensile tests

strain. Eventually, however, after about 15% overstrain there is a considerable recovery of toughness. Now, if the toughness of steel is affected by the degree of yield to which it has been subjected in the test, a modified interpretation of transition-temperature graphs becomes necessary. Consider a characteristic form of temperature-transition graph for an Izod test in which energy to fracture is plotted on a base of temperature (Fig. 2). For a low temperature at *A* the fracture will appear to be 100% crystalline, but, because of yielding, the actual temperature at which the material is 100% brittle has been raised by an unknown amount. At *B*, where considerably more yield has taken place before fracture, the whole area of the fracture is not crystalline in appearance, but there is considerable tearing from the notch and eventually brittle fracture has propagated in a small zone, often crescent-shaped, in the middle of the face. The fracture has become tough again towards the rear side because the greater amount of compressive yield there has rendered the material tough at the temperature of test. Thus, towards the top of the transition curve the amount of material embrittled so that it breaks with crystalline appearance decreases until it eventually disappears altogether. The curve may therefore be regarded as one which depends on, first, the embrittlement with strain and, secondly, re-toughening with further strain, these features alone determining the range of transition temperature. This being so, no reliable information is furnished by the yielding type of notched-bar test as to the actual temperature at which a steel plate would suffer brittle fracture in practice. However, a test that yields the material to induce brittle fracture has a limited application in practice. A ship in collision suffers a certain degree of local yielding which might result in brittle fracture of the type produced by such tests, but this is not a common experience even in welded ships. These conditions are, however, a feature of plastic design.

It might reasonably be assumed that somewhere within the transition range determined by notched-bar tests there is a temperature value which is applicable to the case of catastrophic failure in which a crack propagates right through a plate. Attempts at interpretation to these terms of reference have led to so much controversy that there can be no doubt that some feature common to all the tests is obscuring the real issue. So far as a quality control test is concerned, there is no doubt that notched-bar tests may be used to assess variation from good metallurgical condition, although yielding may affect the temperature at which a crack will propagate. The vast amount of data accumulated from such tests shows that steels in poor metallurgical condition give poor notched-bar results. In the author's opinion, notched-bar tests fail because they do not simulate the practical condition of a propagating crack and because all initiate a crack into yielded material.

As a cause of catastrophic failure of ships' hulls, the incidence of brittle fracture, though not unknown in riveted hulls, has increased very considerably since welding was introduced. The fracture of a plate in a riveted hull does not spread catastrophically, because of the discontinuance of the plate at joints. The weld does not act as an effective discontinuity and, moreover, it is a ready source of incipient cracks and of high residual stresses. Thus, in the welded ship, there is not only a greater chance of starting off catastrophic cracks but also less hope of arresting them once started. A ship is also a highly redundant structure in which it is almost impossible to make precise calculations of stress levels. Many cases of cracks started at positions of unsuspected stress concentration have been recorded. That these cracks do not always propagate may be explained in terms of the stress gradient adjacent to the source but certainly not in terms of temperature alone. Consideration of the number of weld defects inevitable in ship construction leads to the conclusion that propagation of catastrophic failure in a ship requires more than the presence of a sharp crack.

DEVELOPMENT OF A TEST TO ASSESS THE CRACK-ARRESTING PROPERTIES OF MATERIALS

Consideration of steels in terms of their crack-resisting properties has led to the development of a test in which a crack is started in a test piece carrying

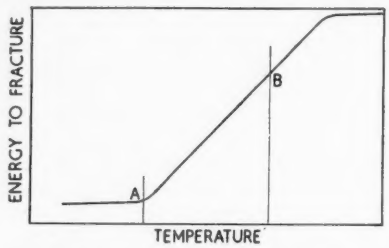


Fig. 2—Typical transition-temperature graph

a known stress transverse to the direction of propagation and in which the crack is arrested because it propagates into material of increasing toughness. Increasing toughness is achieved by raising the temperature along the length of the test piece.

The design of a test piece, in which a crack once started could be arrested, was the first consideration. Various forms of statically loaded test pieces carrying notches designed to start cracks were tried but, generally, those in which considerable strain energy was stored during static loading were unsuccessful. The crack was either uncontrollable or else general yielding of the plate preceded fracture. By using the form of test piece shown in Fig. 3*a* some success was achieved. The crown of the test piece was the only part yielded by the static load when the whole test piece was cooled to a very low temperature. After a certain amount of strain at the crown, during which the wedging action of the yielded material increased the transverse tension at the notch, a crack suddenly started there and propagated for some distance along the length of the test piece. Reproducibility of results was very poor; the load to fracture, the amount of strain before the crack started, and the length of the crack showed extreme variability. Shock loading to start the crack was then tried; the specimen was cooled to a uniform temperature and the crown was subjected to a rapid series of blows from a heavy pneumatic hammer. A crack was easily started at the notch and it propagated farther into the length of the test piece at each blow of the hammer. Eventually, gross yield of the material appeared at the end

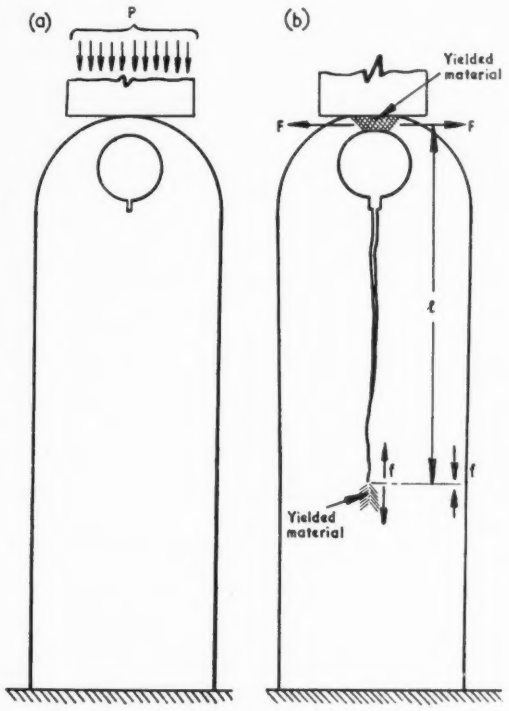


Fig. 3—Preliminary experiments in crack propagation

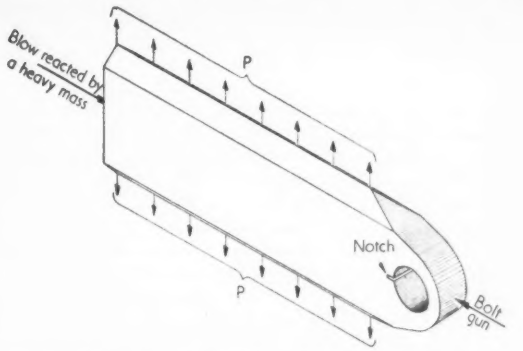


Fig. 4—Robertson transition-temperature test piece

of the crack. Much later it was found that this yield was due to the longitudinal stress set up by the bending action to which the two cantilevers formed by the crack were subjected by loads F at the yielding crown acting at leverage l (Fig. 3*b*). This type of test was pursued for some time before its limitations were realized. Next, a temperature gradient was introduced along the length of the test piece to give variable brittleness, the idea being that the crack would stop at the temperature at which the material became tough. This appeared to be so, but the temperatures, while following the Lehigh and Tipper test results, all proved to be much lower than those experienced in service. The test must therefore be regarded as but another qualitative one which would provide no new information.

A means for arresting a crack had been successfully developed and further thought showed what was lacking. In the reported cases of catastrophic failure in ships, one or both of two conditions may be present, *viz.*, a fall in ambient temperature and the incidence of storm conditions. Fractures have been experienced in dock and in tropical seas. Changes in ambient temperature were reproduced in the temperature gradient of the test, and the other variable—stress—was judged to be important. Effort was then directed to devising a test piece which would carry a known stress transverse to the direction of propagation of the crack. Estimates of stresses likely to be important in practice were put at a low figure, about 5 tons/sq. in. Having a testing machine capable of applying a load of 200 tons and aiming at tests on 2-in. thick material, a stress of twice the expected value would be possible with a test piece 10 in. long.

The test piece is shown in Fig. 4. It is flame-cut to profile and flame-bevelled along its edges in preparation for welding. The drilled hole is 1-in. dia. and the sawcut, $\frac{3}{16}$ in. deep, is made by an ordinary hacksaw blade, ground down to 0·02 in. thickness. No precision machining is required and consequently the cost of preparation is only a fraction of that for Izod and Charpy test pieces.

Economy of material for tests could only be achieved by welding test pieces into a test rig. The rig would have to be fairly long to distribute the load evenly along the test piece through pins in the lugs, so that the maximum span available between jaws in the machine was utilized. Welding the test piece into the

lugs would introduce heavy residual stresses into the test length, so distance pieces made from thinner material than the test piece were welded between it and the lugs. These pieces were yielded when the test piece (shown cracked in Fig. 5) was assembled in the testing machine, before the test proper was made. This yield resulted in plastic flow, both in welds and in distance pieces, sufficient to relieve any residual stresses. The load on the testing machine was then pulsated at a slow cyclic rate of about 10 cycles/min. A Huggenberger tensometer of 1-in. gauge length, fitted with a third leg to make it kinematically stable, was pushed into contact with the surface of the test piece at successive positions along its length, and the strain amplitude readings were observed. This method of stress probing, developed at the Naval Construction Research Establishment, is becoming generally recognized to have a very wide field of application in structural testing.

The strain readings, while reasonably constant along each face, differed in value on the two faces. This, of course, was caused by bad alignment before welding the test piece to the distance pieces. This error was corrected by sliding the lugs backward or forward on the pins in the forked ends so that the line of pull passed truly through mid-thickness of the test piece. By trial, the strain was adjusted to equality on both sides and the load was adjusted statically to give a strain appropriate to the stress for test.

Liquid nitrogen was used to cool the end of the specimen carrying the notch. First, two dished cups were fitted over the hole in the end of the specimen by means of a through bolt. Lead washers between the caps and the specimen made the joint liquid-tight. A Dewar flask containing 10 lb. of liquid nitrogen was mounted near the test piece. Even in a Dewar flask the nitrogen boils away at a continuous slow rate. A well-lagged copper syphon pipe reaching nearly to the bottom of the flask was led uphill from the flask and entered one of the caps through a hole in the top of its flange, giving access to the metal of the specimen. Venting holes were drilled in the top of the other cap so that liquid nitrogen introduced through the one cap would evaporate in contact with the specimen and be exhausted to atmosphere through the other cap.

Control of the delivery rate of the liquid nitrogen was achieved as follows: The upper end of a piece of copper tube of the same diameter as the exit tube of the flask and about 3 in. long was brazed to the syphon tube. The lower end was sealed to the flask exit tube with adhesive tape. The evaporation inside the flask caused the liquid nitrogen to rise in the syphon tube and commence delivery to the test piece. From a **T**-connection to the 3-in. tube a rubber tube was led to a stand pipe, which could be lowered into a cylinder of water to give the necessary back pressure to regulate the flow of nitrogen to the specimen. A temperature of $-100°$ C. at the notch is easily obtained with a consumption of nitrogen of $\frac{1}{2}$ lb./min.

The other end of the specimen was heated by a gas flame. A sensitive thermocouple was made by brazing the couple wires together, butting the ends. The junction was then flattened by hammering until not more than 0·005 in. thick and bent into a hoop. This enabled the couple to be pressed into contact with the surface of the test piece. The surface of the test piece was polished, using an electrically driven portable sander. Two rows of centre-punch marks were made at $\frac{1}{2}$-in. intervals along the length. Each row was 1 in. distant from the centre-line along which the crack was expected to propagate, and each fifth position was doubly centre-punched for easy identification. A thermocouple and its calibrated galvanometer were arranged to give a continuous reading at the warmed end of the specimen and the gas flame was adjusted to maintain the desired temperature there. Delivery of liquid nitrogen was then started at the other end of the specimen and the flow was adjusted until conditions of temperature gradient were stable. The temperature along the gradient was measured using the very thin portable junction. The surface of the test piece was wetted with fairly pure methylated spirit, which does not freeze above about $-100°$ C. This disposed of the layer of frost which otherwise soon built up on the surface and made temperature measurements difficult. The couple was pushed against the wet surface—evaporation of the spirit being negligible at these low temperatures—and lined up on the expected crack line between matching centre-punch marks above and below. The doubly centre-punched marks were used to check records of temperature as written down, and traverses along the specimen were made until the temperature gradient showed stability and approximately the desired terminal values. By moving only $\frac{1}{2}$ in. along the test piece from reading to reading, with a temperature drop of about 5° C., the settling time for the couple was kept to a minimum, and a high-speed, well-damped, 'Flik' Cambridge galvanometer helped to attain the desired accuracy of $\pm 1°$ C. in the measurement of temperatures along the gradient.

The effect on stress distribution of a non-uniform temperature gradient has been studied. A uniform gradient would mean uniform contraction from the hot to the cold end and uniform stress along a pin-jointed specimen, but a non-uniform gradient would introduce stress change along the length. To investigate this, seven Huggenberger tensometers were attached to points along the length of a specimen mounted in lugs. The whole specimen was then cooled uniformly and slowly by piling solid CO_2 on the lugs, baffles being fitted to avoid circulation of CO_2 gas over the surface of the test length. The change of reading appropriate to change of temperature was noted for each gauge. In a second experiment, liquid nitrogen was delivered to the caps at the notched end at a steady rate, as in testing, but no heat was applied to the other end. This produced a temperature gradient that varied from 16° C./in. near the cooled end to 1° C./in. near the other end. Huggenberger readings, corrected for temperature change, showed that the maximum variation of stress from the mean did not exceed $\pm \frac{1}{2}$ ton/sq. in. The gradient in normal tests where one end is cooled and the other is heated is uniform over two-thirds of the 10-in. test length, so that there can be no question of stress inaccuracy due to the gradient used in practice.

A duration of about 20 min. was sufficient to establish a gradient with the cold end at $-70°$ C.

Fig. 5—Crack-arresting test in tensile testing machine

Fig. 6—Ductile arrest with thumbnail marking

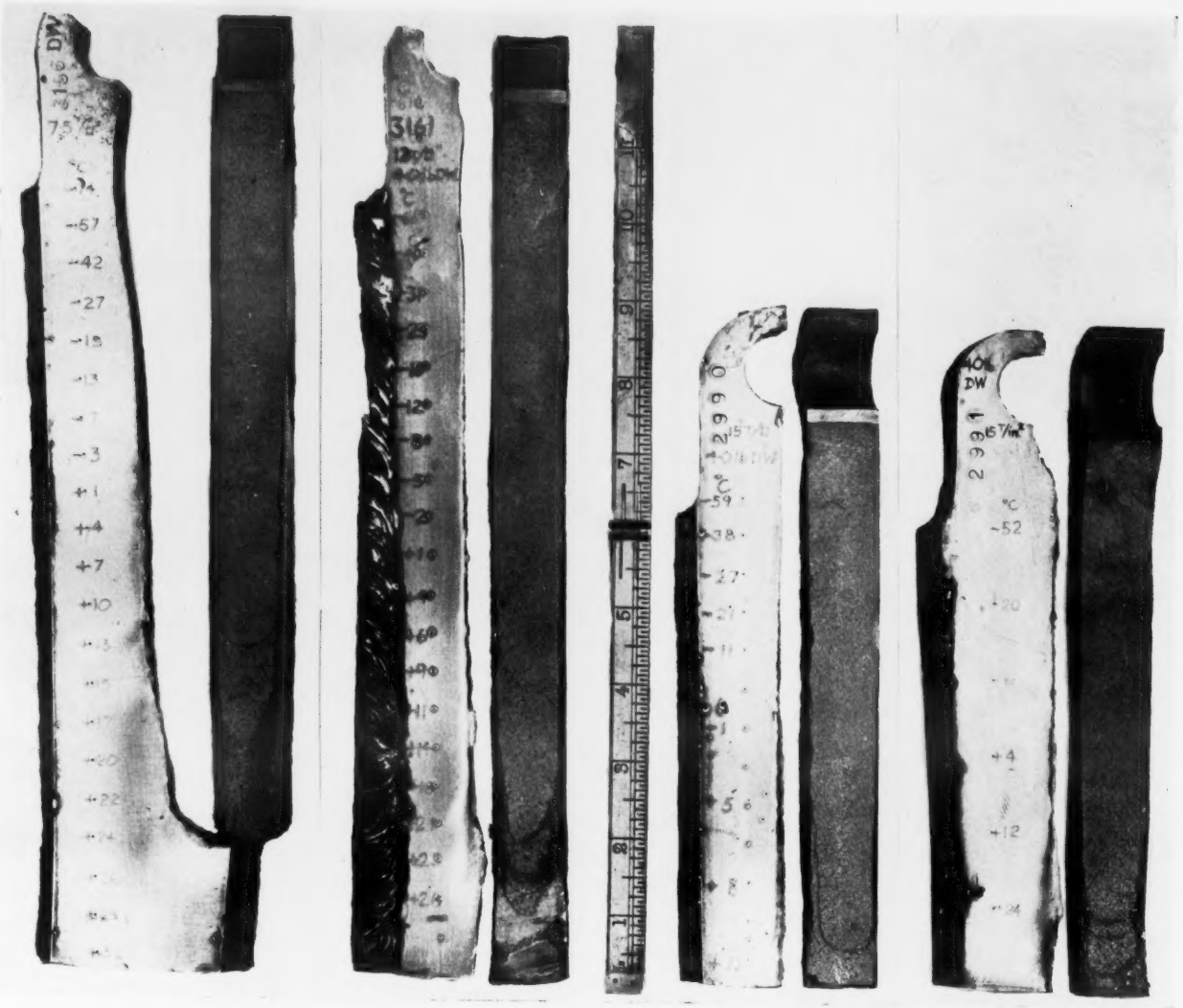


Fig. 7—Crack-arresting test specimens with widely different temperature gradients

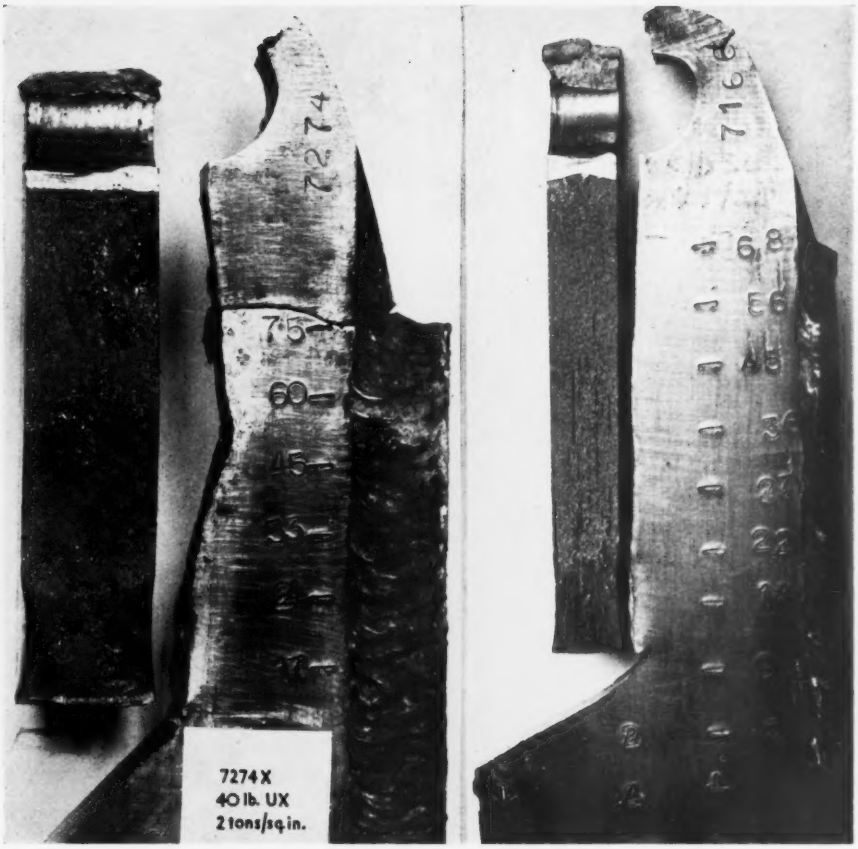
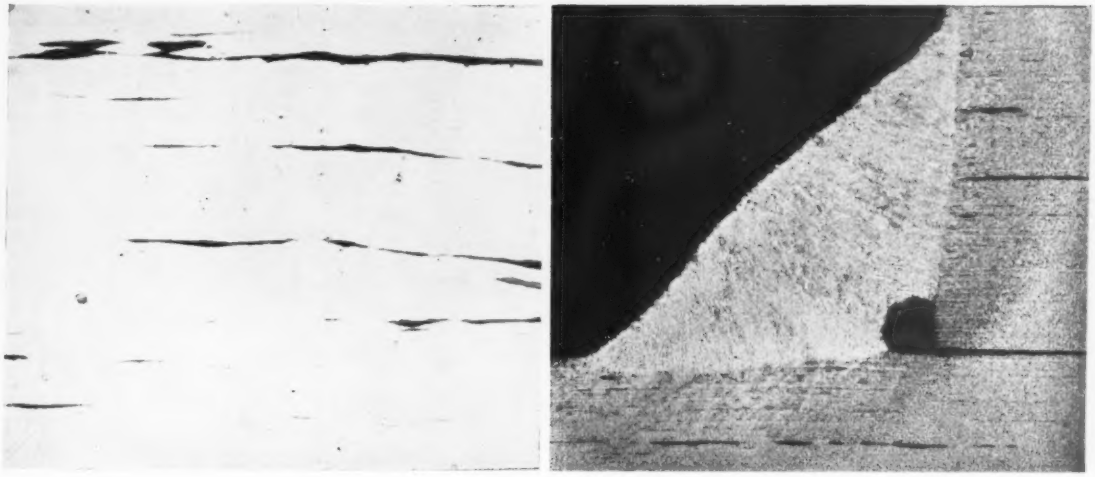


Fig. 8—Critical stress arrest

Fig. 9—Arrest of fracture in plate *UL*

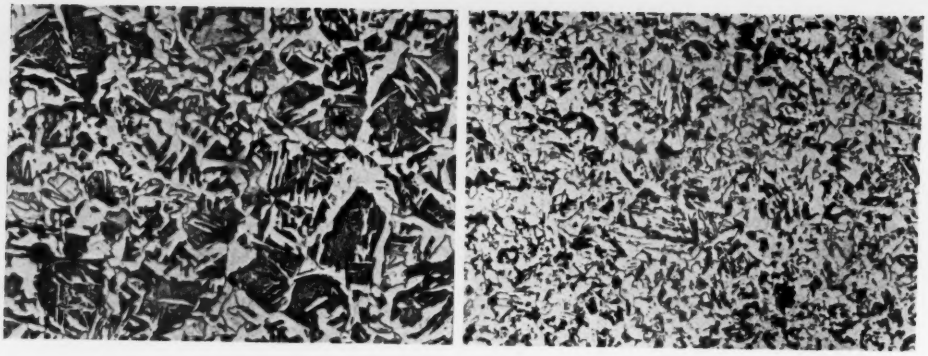
(a) (b) (c) (d)

Fig. 7—Crack-arresting test specimens with widely different temperature gradients



(a) (b)

Fig. 10—Plate *UL*: (*a*) Inclusions in polished section × 100; (*b*) etched section of fillet weld × 5



(a) (b)

Fig. 11—Plate *WK*: (*a*) As-received; (*b*) normalized from 860° C. × 100

(a) (b)

Fig. 12—Fracture tests at: (*a*) − 5° C.; (*b*) + 4° C.

and the other end at + 60° C. About 7 lb. of liquid nitrogen were used.

Figure 5 shows that the first rig has a frame carrying a mass of about 200 lb. of steel, which bears against the warmed end of the specimen. This formed a buffer to react the blows of the pneumatic hammer mounted opposite the heavy mass.

When the desired temperature gradient had been established along the test piece the rounded end was given a short burst of blows from the pneumatic hammer, perhaps about six in number. This started a running crack which propagated at high speed along the length of the test piece, showing little tendency to deviate from a centre-line. In later tests a bolt gun delivering a single high-speed blow replaced the hammer.

The crack was arrested by the material at a temperature determinate in terms of the applied transverse stress. The first material tested was a mild steel, which in Tipper, Lehigh, and Izod tests was considered to be tough. The fracture faces and the polished surface are shown in Fig. 6 for a test made with a transverse stress of 10 tons/sq. in. The temperature gradient rose from — 85° C. at the notch to + 40° C. at the warmed end. Examination of the polished surface shows that the arrest was followed by gross general yielding of the whole of the remainder of the test piece. When the test piece was broken open to show the fractured surfaces a characteristic thumbnail marking was found at the root of crack, where it had arrested. This is well shown in Fig. 6 and is characteristic of many fractures found to have arrested in practice. The temperature, + 5° C. in this case, at which gross yielding took place on the surface was easily identified and was called the ' arrest temperature.'

It was necessary to check that the results in this crack-arresting test which produced fractures that looked like those arrested in practice were not conditioned by (*a*) the geometry of the test piece, or (*b*) the temperature gradient. To do this, test pieces of different lengths and with widely differing temperature gradients were tested. Such a series is shown in Fig. 7, where the first arrests (as defined later) all lie in the range 9–12° C. The temperature gradient must not be less than 8° C./in. to give a good clear arrest. The test piece in Fig. 7*b*, shown with a gradient at the first arrest of only 4° C./in., makes this clear.

Some of the tests at the higher values of transverse stress produced more than one arrest, that is, the fracture arrested, restarted, and was again arrested. The markings on the polished surfaces of test pieces always showed that general yield of the material had taken place in the zone between the first and second arrests. The fracture in Fig. 7*a* shows this clearly.

In designing the test, some thought had been given to the mechanics of propagation of cracks in catastrophic failure in ships. Accounts of the casualties postulated speeds of propagation of about 4000 ft./sec. The maximum length of test-piece assembly which could be fitted was therefore used in an attempt to ensure that, during the propagation of the crack in the test piece, the stress would not alter in the unbroken part. It is generally accepted that, in practice, there is not time for the stress to alter in consequence of reduction in the load-carrying section of the plate before the high-speed crack has passed right through the plate. To understand this it is necessary to visualize the action of a stress wave in the material. To effect a change of stress in the unbroken section past the end of the propagating crack, the wave of relaxation of tensile stress at the crack surface must travel out into the plate in a direction perpendicular to the crack until it meets a discontinuity that will reflect the compressive wave (for relaxation of tension is, after all, compressive) as a wave of tension which, in due course, will reach the unbroken section. Since this stress wave may have to traverse many feet of plating before encountering a discontinuity, there is practically no chance of the reflected wave catching up on the fracture. The maximum length available in the testing machine was about 6 ft. and this permitted a test piece with an effective length in the direction of travel of the stress waves of 24 in., or a path length of 4 ft. This would mean that for a crack 6 in. long a speed of propagation above 2000 ft./sec. would ensure that the stress had not altered during the progress of the crack.

MEASUREMENT OF SPEED OF PROPAGATION

A camera capable of photographing 4000 frames/sec. was available and films of the fracture were taken at this speed. In none of about a dozen successful results with cracks 6–8 in. long did the photographs reveal other than that in one frame there was no crack while in the next frame a full-length crack appeared. This means that the speed of propagation must have been well in excess of 2000 ft./sec.—probably 3–4 times as high. Most of these tests were made at a transverse stress of 10 tons/sq. in. Later, an electronic timer became available and measurements approximating to the speed of cracking were made. The electronic timer, capable of measuring times of the order of 1 μ sec., requires that the event, in this case a crack, should break two circuits in succession, the first break starting and the second break stopping the timing operation. Thin wires such as are used on wire resistance gauges were not suitable since a yield of 7–10% is possible before the wires break. No reliance could be placed on figures obtained where any considerable strain before breaking was involved, since the elastic recession of the material on the two sides of the crack would be extremely small. Later, at the speed of follow up of the rest of the machine the crack would open up wider and possibly only the speed of this opening would be measured.

After a number of preliminary experiments a successful technique was evolved. Strips of graphite-coated paper, $\frac{1}{8}$ in. wide, were heated in contact with a soldering iron until the paper was baked deep brown and retained just sufficient toughness to allow handling. Two of these strips were then stuck to the test piece near the notch at 1-in. intervals by a very thin coat of cellulose varnish. The resistance was about 10,000 ohms and suitable impulsing circuits were added to trigger the electronic counter. Speeds of around 6000 ft./sec. were recorded near the notch for stresses of 10 tons/sq. in. These speeds fell to about 4000 ft./sec. as the stress was reduced to 6 tons/sq. in. Further from the notch, however, near

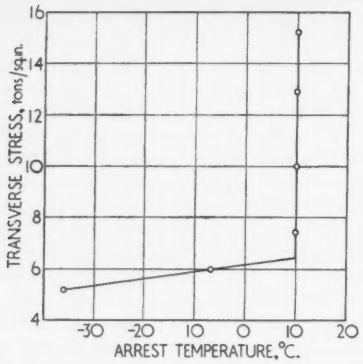


Fig. 13—Characteristic stress/arrest-temperature graph: 40-lb. plate *WV*

the position of arrest the measured speeds fell off to about 1500 ft./sec. Careful examination of the specimens showed a lip of surface yield to be well developed at this position, and the question arises whether this yield does or does not take place at the slower speed of follow up of the machine while the crack passes along underneath at high speed. Only measurements taken nearer the notch are at present reliable. This doubt about the effect of surface yield might be resolved by measuring the rate of growth of the actual area cracked. Such a method might measure the change in electrical resistance of the test piece while the crack propagates.

ASSESSMENT OF ARREST TEMPERATURES

Having established that the test gives consistent results it was necessary to decide on a criterion for the assessment of arrest temperatures. The tests on pieces with highly polished surfaces were helpful as they showed the yield clearly. The temperature at the position where this yield ran out from the crack into the plate (Fig. 6) was determinate to within 1° C. However, in tests made at lower stress values there is a very considerable drop in arrest temperature for a small decrease in transverse stress. Under these conditions there is no marked yield on the surface and it is necessary to open up the specimen to observe where, in fact, the crack has stopped. Examination of many test pieces cracked at stress values of 6–12 tons/sq. in. showed that the beginning of gross surface yield did not coincide with the end of the crack but with the focus of the curve forming the thumbnail marking. Polishing was discontinued and the temperature at this focus was used in assessment of results.

OPENING-UP AND PRESERVATION OF FRACTURES

The usual operation in opening up specimens for inspection consists, first, immediately after fracture, in heating the test piece by an induction heater to above boiling point to remove any condensed moisture from the crack surfaces. The test piece is then flame-cut from the lugs and a **V**-notch is cut in from one side to mid-width at a position just below that estimated for the end of the crack. The temperature values are stamped on the cleaned face, and the crown, if not already cracked, is sawn through. The bottom of the specimen, with its width straddling the jaws, is gripped firmly in a vice, and a hammer and drifting chisel are used to force open the fracture. Tearing takes place from the actual end of the crack to the bottom of the **V** with considerable local yeilding. In a material with a crack-arresting temperature above atmospheric this yielding may lead to repropagation of brittle fracture. This can be avoided by heating the specimen before opening up until oil dropped on the surface begins to smoke. After breaking open, the test piece is allowed to cool and is immediately coated all over with cellulose varnish. With reasonably dry storage this coating will preserve the specimen for months against rusting. The coating can always be removed with acetone for closer examination or photography of the surface of the fracture.

RELATIONSHIP BETWEEN STRESS AND ARREST TEMPERATURE

The curve of Fig. 13 is considered to be characteristic of the behaviour of a tough steel subjected to the test. The higher temperature arrests, leading to yield at the root of the crack after arrest, all occur at the same temperature value. This temperature has been named the ' ductile arrest temperature.' When the temperature for arrest falls below this value there is a critical relation between stress and temperature. Thus, a ' critical stress value ' must be allied to a temperature. These critical stress arrests have not the same thumbnail markings as the ductile arrests; they are much more abrupt (*see* Fig. 8).

DEVELOPMENT OF A SPECIAL MACHINE FOR THE TEST

It was soon realized that work on crack arresting would monopolize a very versatile machine, so a simplified form of crack-testing rig was designed and manufactured. The general arrangement is shown in Fig. 14. A precision type of loading device was unnecessary as Huggenberger tensometers are used on each test piece to determine the actual elastic strain, but a number of Macklow-Smith hydraulic capsules rated at 250 tons load were available, and two of these, one on each machine, have been used continuously for well over a year. The load of 250 tons has been exceeded by 100%, and an additional feature of $\frac{1}{4}$-in. movement of the rubber-bonded piston has, with the makers' consent, been employed with complete success. The operation of the machine would be simplified by the use of a simple packed piston of 500 tons capacity and about 2-in. stroke in place of the capsules.

The machine consists of a pair of simple levers loaded at mid-length by the capsule, with two rods at the back carrying approximately the same load as the test piece. The test piece is welded into distance pieces connected to lugs which have circular holes at their ends. These holes seat semi-circular inserts spherically seated on their inner surface. The spherical seatings engage with two spherical loading pins, one at the end of each lever. When the distance pieces have yielded so that they have stretched about 5%, the strain in the test piece, though uniform along its

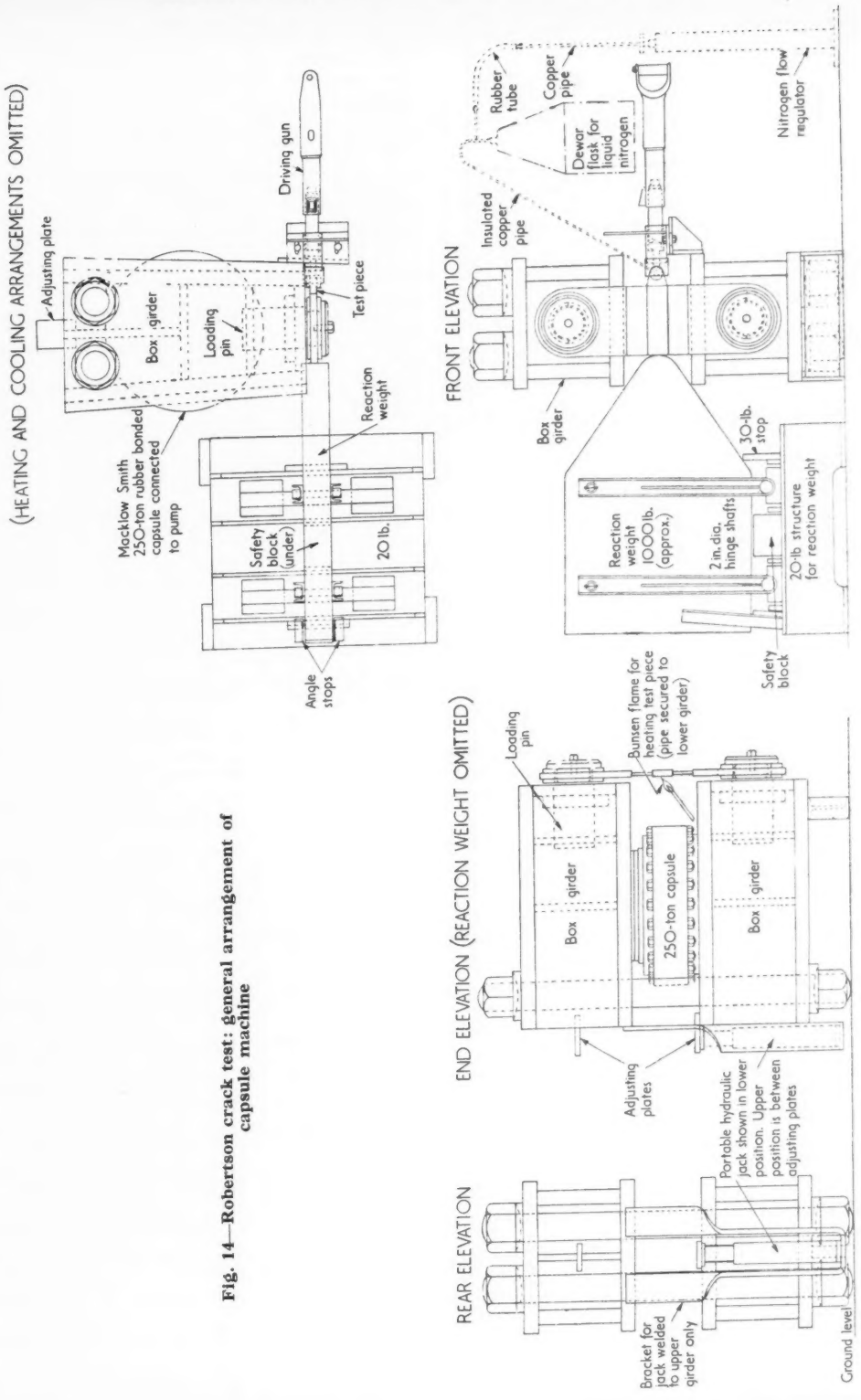
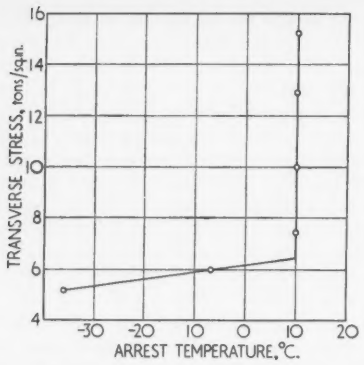


Fig. 14—Robertson crack test: general arrangement of capsule machine



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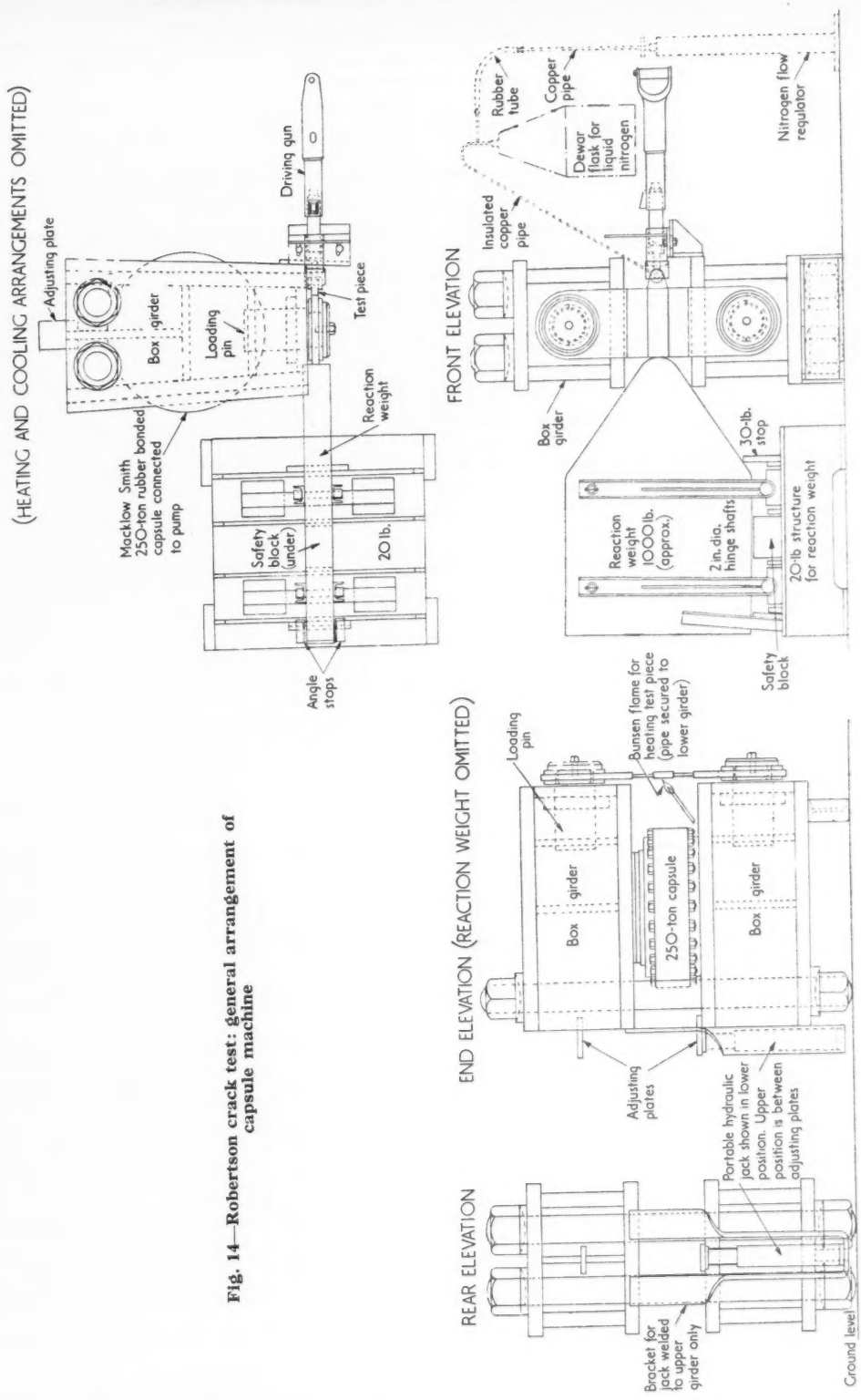

Fig. 14—Robertson crack test: general arrangement of capsule machine

Table I—PHYSICAL PROPERTIES OF PLATES TESTED

Plate	Chemical Composition, %								Tensile Properties				Remarks	
	C	Si	Mn	P	S	Ni	Cr	Mo	Direction	Yield Stress (Tons/sq. in.)	U.T.S. (Tons/sq. in.)	Elong., %, on 8 in.	General	Macro-Banding
MSD	0·15	0·07	0·48	0·023	0·032	0·13	0·08	0·04	L X	17·8 17·5	26·6 26·8	27 31	Fine structure: carbide pearlitic	
MSK	0·14	0·05	0·65	0·040	0·028	0·05	0·07	Nil	L X	15·6 15·7	27·0 26·3	30 27	Fine structure: some grain-boundary carbide	Two faint dark bands
MSL	0·15	0·04	0·47	0·037	0·057	0·07	<0·02	0·04	L X	14·9 14·7	26·4 26·0	27·5 24·0	Medium structure: carbide mainly pearlitic	Two faint bands
MSM	0·15	0·03	0·58	0·027	0·032	0·04	0·02	0·02	L X	15·3 15·3	25·6 25·8	32 28	Fine structure: some grain-boundary carbide	Very faint dark and light bands
MSX	0·16	0·05	0·64	0·034	0·044	0·14	0·06	0·04	L X	14·9 14·5	27·2 27·3	29 32	Medium structure: carbide pearlitic	Very faint band
MSY	0·18	0·03	0·64	0·031	0·039	0·03	0·03	<0·02	L X	14·6 14·3	27·4 26·5	34 34	Medium structure: some grain-boundary carbide	No band visible
MSZ	0·15	0·02	0·63	0·024	0·046	0·03	<0·02	<0·02	L X	12·6 13·0	25·4 25·7	35 33	Medium structure: some grain-boundary carbide	Very faint bands
ND	0·20	0·17	0·87	0·031	0·053	0·20	0·06	0·05	L X	20·9 22·4	30·8 31·7	28·5 26·3	Very fine, banded structure: carbide mainly spheroidal	
NK	0·20	0·05	0·99	0·031	0·038	0·13	0·06	0·04	L X	18·0 17·8	30·9 30·1	29·2 24·0	Fine, banded structure: carbide partly spheroidal	No visible banding
NL	0·18	0·04	1·24	0·010	0·030	0·46	0·09	0·06	L X	19·9 21·2	32·6 33·5	26 26	Medium structure: carbide mainly pearlitic	Marked central band
NM	0·20	0·03	1·05	0·018	0·023	0·08	0·04	0·03	L X	18·9 18·7	31·8 31·0	31 28	Fine structure: carbide pearlitic	Two faint dark bands
NX	0·21	0·04	1·05	0·018	0·024	0·09	0·04	0·05	L X	18·7 18·6	30·9 30·7	29 28	Fine, banded structure: carbide pearlitic	Two dark bands
NY	0·19	0·02	1·27	0·024	0·031	0·27	0·04	0·06	L X	20·8 20·7	33·4 32·9	27·5 30	Fine, banded structure: carbide pearlitic	Two dark bands
NZ	0·21	0·05	1·25	0·037	0·034	0·15	0·07	0·05	L X	20·4 19·8	34·7 31·5	31·5 31·0	Fine, banded structure: carbide spheroidal	
UD	0·18	0·04	1·26	0·023	0·029	0·27	0·04	0·04	L X	23·3 24·2	32·9 33·0	27 22	Very fine, banded structure: carbide pearlitic	
UG	0·19	0·03	1·26	0·024	0·030	0·27	0·04	0·05	L X	23·3 24·0	34·8 34·3	22·5 22	Very fine to fine, banded structure: carbide mainly pearlitic	Strongly marked dark band
UK	0·18	0·03	1·26	0·023	0·029	0·28	0·04	0·06	L X	20·2 20·9	32·9 33·2	25 21	Medium structure	Broad strongly marked dark band
UL	0·18	0·12	1·46	0·027	0·035	0·06	0·04	0·02	L X	21·8 20·2	32·6 30·9	27 24	Fine structure: carbide pearlitic	No band visible
UX	0·19	0·02	1·26	0·022	0·031	0·27	0·05	0·06	L X	18·6 18·2	32·5 32·7	27 26	Medium structure: carbide pearlitic	Two to four strongly marked bands
UY	0·18	0·12	1·55	0·032	0·049	0·07	0·04	0·02	L X	20·7 20·5	34·2 34·9	27 21·5	Medium structure: carbide pearlitic	Broad strongly marked dark band
UR	0·19	0·02	1·24	0·021	0·029	0·27	0·05	0·06	L X	19·0 20·5	31·8 33·4	24·5 23	Coarse structure: carbide pearlitic	One to four marked band
WD	0·22	0·06	1·50	0·022	0·027	0·09	0·05	0·10	L X	25·9 26·8	39·8 38·8	14 17	Very fine structure: carbide part pearlitic, part spheroidal	Very faint light bands
WK	0·21	0·03	1·44	0·014	0·030	0·08	0·05	0·03	L X	20·3 20·6	34·1 34·6	20·4 22·5	Coarse structure: carbide mainly pearlitic	Narrow central band
WL	0·22	0·06	1·54	0·038	0·040	0·09	0·07	0·04	L X	25·5 25·2	36·2 36·9	20 17·5	Fine to coarse, mixed, structure: carbide pearlitic	Two marked bands
WN	0·21	0·12	1·63	0·039	0·050	0·06	0·06	0·04	L X	22·5 21·9	38·5 37·0	18·8 19·1	Coarse structure: carbide mainly pearlitic	Wide central band
WX	0·21	0·03	1 48	0·025	0·033	0·08	0·05	0·03	L X	19·4 20·1	34·3 35·0	27·6 27·1	Coarse structure: carbide pearlitic	Broad faint dark band
WY	0·20	0·10	1·41	0·029	0·027	0·03	0·03	0·02	L X	19·3 19·9	34·3 34·8	29 27	Coarse structure	Two dark bands
WZ	0·22	0·03	1·51	0·025	0·030	0·15	0·07	0·04	L X	21·1 22·1	36·8 37·5	27 24	Coarse structure	Two dark bands
WV	0·23	0·02	1·38	0·017	0·041	0·12	0·04	0·04	L X	17·7 ..	35·3 ..	28·5 ..	Medium structure, banded: carbide mainly pearlitic	

length, may be different on the two surfaces. This difference is corrected by sliding the lugs over the spherically seated inserts by an amount which is determined experimentally by the operator. The pressure in the capsule at which the uniform strain representing the required testing stress is reached on the four extensometers is noted and maintained during the test. A mass of about 1000 lb. rests against the undrilled end of the test piece so that the blow from the bolt gun will be reacted and will thus not result in a large bending strain in the test piece assembly.

One of the main features of the machine is that the spherically ended pins allow the test-piece assembly to be moved in or out on the sleeves so that the necessary correcting bending moment can be applied to counterbalance misalignment in welding.

On changing over to this machine, use of the pneumatic hammer was discontinued. In its place a bolt gun fires a high-speed bullet into contact with a trapped plunger which delivers the single blow to the specimen. This disposes of the fear that repropagation of the crack due to continued blows from the hammer might occur after a first arrest. Different series of tests were in progress during the change-over and some of the stress values were duplicated. The results were in complete agreement. A second machine has since been made and both are fully occupied on an extensive survey of the crack-arresting properties of steels in current use.

INVESTIGATION INTO THE CRACK-ARRESTING PROPERTIES OF A SERIES OF STEEL PLATES

Four steels were chosen as differing sufficiently in analyses and heat-treatments to cover the field of structural steels; each has been supplied to a different Admiralty specification:

Mark	Type
MS	An ordinary mild steel, as used for general structural work
N	Slightly higher tensile steel in normalized or annealed condition
U	Same steel as *N*, but as-rolled
W	Weldable steel of still higher tensile strength.

The additional key letters used to indicate the poundage or thickness of the plate are as follows:

Mark	*D*	*G*	*K, L, M, N*	*R*	*V, X, Y, Z*
Weight, lb./sq. ft.	15	20	25	35	40
Thickness, in. (approx.)	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{7}{8}$	1

Thus, *MSD* indicates a 15-lb. mild-steel plate. Three plates of each quality in each of the groups $\frac{1}{2}$, $\frac{5}{8}$, $\frac{7}{8}$, and 1 in., and one plate of each quality in $\frac{3}{8}$ in. thickness have been tested. Analyses, results of mechanical tests, and the metallurgical characteristics of the plates are given in Table I. The analyses were made on one end of the broken tensile test pieces at the Bragg Laboratory, Sheffield. Graphs of the test results are reproduced in Fig. 15.

DISCUSSION OF THE TEST RESULTS IN TERMS OF PLATE QUALITIES

40-lb. Plates

The ductile arrest temperatures for *MSX*, *MSY*, and *MSZ* are all clearly defined. The knee at the end of the critical stress line is well marked. The stress value at change from critical stress to ductile arrest varies only from $4\frac{1}{2}$ to $6\frac{1}{2}$ tons/sq. in.

Plates *NX*, *NY*, and *NZ* show a wide range of ductile arrest temperatures from 23° C. down to 0° C. and indications of a step between the stress values of 4 and 7 tons/sq. in. are found. These three plates,

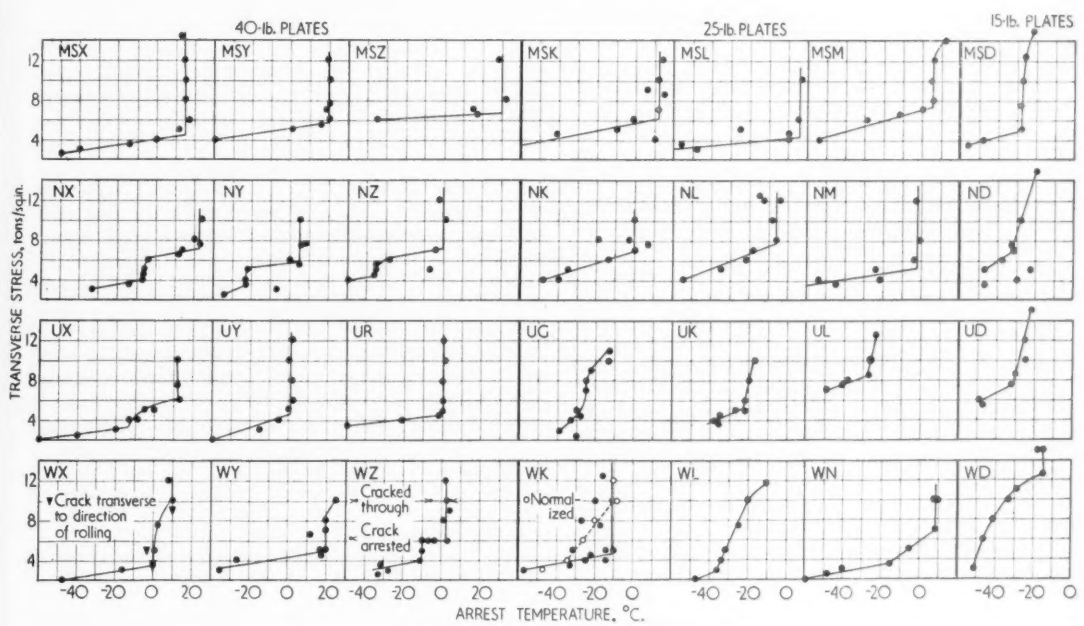

Fig. 15—Graphs of test results

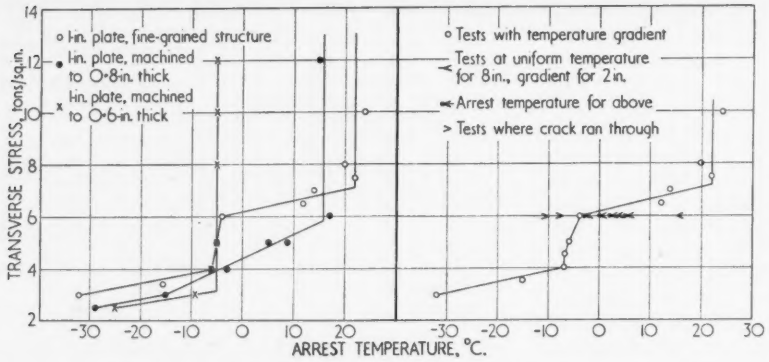
o 1-in. plate, fine-grained structure
• 1-in. plate, machined to 0·8-in. thick
x 1-in. plate, machined to 0·6-in. thick
TRANSVERSE STRESS, tons/sq.in.
ARREST TEMPERATURE, °C.
o Tests with temperature gradient
Tests at uniform temperature for 8 in., gradient for 2 in.
Arrest temperature for above
> Tests where crack ran through

Fig. 16—Thickness effect in plate *NX*

Fig. 17—Assessment of arrest temperature

which were normalized as-received, are of interest in that they are all fine-grained ferritic. Izod tests on these plates show them to have lower transition-temperature ranges than any of the other qualities. The Izod tests do not, however, differentiate between the plates sufficiently well to put them in a specific order of merit. The ductile arrest temperatures put *NX* in a very inferior position compared with *NY* and *NZ*. As additional plate in quality *NX* was available some separate investigations have been made on it and these will be described later.

The as-rolled plates *UX*, *UY*, and *UR* give the same types of graph as *MS*, though the graph for *UX* approaches the type for *N* plates. The critical stress values are all low.

Plates *WX* and *WY* again give characteristic results for as-rolled plates. *WZ* follows *NX*. Three special test pieces were made from large pieces of plate *WX*. The whole assembly of lugs and test piece was made in one continuous length with the direction of propagation of the crack arranged transversely to the direction of rolling. The cracks in all other test pieces have been arranged to travel along the direction of rolling, and the excellent agreement in the results, plotted in Fig. 15, shows that in this plate there was no directional effect. The results of notched-bar tests on this plate lead to the same conclusion. Further, this experiment where the distance pieces were omitted shows that the technique evolved for the removal of residual welding stresses by the interposition between test piece and lugs of a yielding distance piece has succeeded in its object.

25-lb. Plates

The ductile arrest temperatures show a marked drop for all qualities of plate, compared with the same qualities in 40-lb. plates. This suggests a thickness effect which may be due to additional hot work, lower finishing temperatures, quicker cooling, or simple geometry. The latter has been investigated in plate *NX* and forms the subject of a later section of this paper.

The mild-steel plates show an average fall of 16° C. in ductile arrest temperature from that for the 40-lb. mild-steel plates. The critical stress values vary just as much from plate to plate and show no change in general stress level from that for the thicker material.

Plates of *N* quality have now lost the distinctive type of graph found for the 40-lb. plates and fall into the general type with a well-defined knee at the end of the critical stress line. The stress values at the knee are much the same as those for the upper knee in the 40-lb. *N* plates. The average ductile arrest temperature has fallen by 11° C. and there is a certain amount of scatter in the results above the critical stress line.

Plates *UG*, *UK*, and *UL* all show a most marked drop in ductile arrest temperatures from those for 40-lb. plates, the average having fallen 30° C. The critical stress values vary considerably. The high critical stress value for plate *UL* is undoubtedly due to the presence of many plate-like inclusions, shown in Fig. 10*a*. These effectively arrest the propagation of the crack, and their presence is easily recognized when the fracture face is examined. There is no thumbnail marking and the end of the crack, in the main normal to the plate surface, is serrated with alternate tough and brittle endings. The surface of the fracture appears striated, with dull lines between which is enclosed a mist of small crystal facets that might have been sprinkled from a pepper pot (Fig. 9). The main disadvantage of such inclusions is their effect on the strength through the thickness of the plate. This renders the plate not easily weldable (Fig. 10*b*). Test pieces cut from thicker materials which suffered from this defect have shown tensile strengths through the thickness of only 8 tons/sq. in.

The *W* quality plates in this thickness are most variable. Plate *WK* showed such variation that additional Izod tests were made on test pieces cut from the edge of the plate for comparison with others cut from mid-width. These gave parallel transition-temperature graphs 25° C. higher. The result of normalizing this plate from coarse to fairly fine-grained ferritic (Fig. 11) is most marked. The variation disappears and the material gives a graph (shown as a broken line) which falls into the category of *WL* (*see* Fig. 15). Plate *WN* gave a high ductile arrest temperature and a graph very like that for 40-lb. *UX*. This as-rolled plate gives poor results in all notched-bar tests and provides an example in which all tests indicate a poor metallurgical condition. Reviewing these results for 25-lb. *W* plates, it can be concluded that this material is one which is capable of giving excellent results but is very sensitive to rolling and finishing temperatures.

15-lb. Plates

Results for tests on only one plate of each quality are shown in Fig. 15. At this thickness, $\frac{3}{8}$ in., it is not possible to propagate running cracks above — 15° C. at quite high stress values. The thickness effect thus provides safety from running cracks under

all likely service conditions. In *MSD* the graph has the characteristic form with the same order of critical stress value at — 40° C. as for *MSX* and *MSK*. The ductile arrest temperature has fallen to — 28° C. Plate *ND* shows some scatter, but arrest temperature is still always below — 20° C. This scatter may reasonably be expected on a normalized plate of this thickness where some form of straightening or flattening process must follow normalizing. Plate *UD* does not show this scatter. Plate *WD* gives a graph very similar to that for normalized *WK*, but lower down the temperature scale. The continuous fall in strength right down to — 50° C. is a notable feature. The upper end of the graph, at stresses above 12½ tons/sq. in., shows a higher temperature arrest than any of the other plates. This plate also gives high values of temperature for the incidence of crystalline appearance in Tipper, Charpy, and Izod results.

DISCUSSION OF THE GRAPHS IN TERMS OF PLATE THICKNESS

Each of the qualities shows a decided fall in ductile arrest temperature with decrease in plate thickness. In the mild steel the real effect of decrease in thickness does not show up until the thinner plates, *i.e.*, those below ½ in. thickness, are tested. In the normalized steel *N* the same holds, but in the as-rolled qualities other than mild steel, plates ⅝ in. thick show a decided superiority over those of 1 in. thickness.

Having established that steels in the as-rolled condition do show a thickness effect in crack-arresting properties, it remains to establish whether this effect is wholly due to the rolling process or whether it can be produced by thickness alone.

THICKNESS EFFECT INVESTIGATED IN 40-LB. PLATE *NX*

This plate had a fine-grained ferritic microstructure and gave none too good results in tests on 1 in. thickness. Additional plate was available and was used to investigate whether, by machining away material to produce a thinner plate, the thickness effect could still be demonstrated. Test pieces were machined to remove equal amounts from each surface of the 1-in. plate until thicknesses of 0·8 in. and 0·6 in. were reached. The results of tests on these thinned-down plates are reproduced in Fig. 16. These graphs make it immediately clear that exactly the same order of fall in ductile arrest temperature results as when the plates are rolled down to the same thickness and normalized. The results for the 0·6-in. thick plate are comparable with those for *NM*. The fall in ductile arrest temperature for the removal of the first 0·2 in. is much smaller than that for the removal of the second 0·2 in. It can be concluded that there is a well-defined thickness effect due to geometry alone.

VALIDITY OF THE METHOD OF ASSESSING ARREST TEMPERATURES INVESTIGATED IN PLATE *NX*

In the early tests, when both surfaces of each test piece were highly polished, the incidence of yielding at the end of the crack indicated the focus of the thumbnail marking as a useful means for identifying the temperature for ductile arrest. This was adopted and in only a few cases where the arrest temperatures are much above atmospheric is any degree of skill required in assessing the results. The difficulty arises over the possible propagation of further brittle fracture in opening up the specimen. As mentioned earlier, this difficulty can be overcome by breaking open the specimen at a temperature well above that for ductile arrest. However, arresting the crack on a temperature gradient might give results which would not be in accord with the temperature at which a crack would not propagate in a plate at uniform temperature in practice, so it was decided to test a number of specimens cut from plate *NX* with different values of uniform temperature along their length at a transverse stress of 6 tons/sq. in. This value was chosen because the arrest temperature remains constant in this material from 4 to 6 tons/sq. in. It was considered necessary to cool the nose of the test piece to start a running crack, the opinion being held that any notch is less effective in propagating fracture than a natural crack. The local cooling would introduce local tension in the zone at lower temperature and this would result in a slight reduction in the applied tensile stress in the zone at constant temperature. Since the graph falls practically vertically at 6 tons/sq. in. this fall in stress would not vitiate the experiment. The results, plotted in Fig. 17, substantiate the criterion adopted for assessment of arrest temperatures.

Two further tests at constant temperature were made on material *WZ* with a uniform transverse stress of 10 tons/sq. in. at + 4° C. and at — 5° C. The results are plotted in Fig. 15, and Fig. 12 shows the fractures. The fracture in Fig. 12*a* was tested at — 5° C. and the crack ran right through. The chevron markings on the surface of the crack become clearer as the crack proceeds, indicating that these markings are consistent with the establishment of stable conditions of propagation. This same effect is found in practice, the general statement being that the chevron markings point towards the source of fracture. About midway along the length of the surface of the fracture at + 4° C., Fig. 12*b*, will be found an elongated thumbnail arrest, followed by subsequent repropagations in the slightly yielded material of the rest of the test piece.

COMPARISON BETWEEN CRACK-ARRESTING TESTS AND TIPPER, LEHIGH, AND IZOD NOTCHED-BAR TESTS

The degree of correlation between notched-bar tests and actual casualties is one of the most controversial issues in this subject of brittle fracture. Generally it is agreed that there is a certain degree of inter-relation between the results of notched-bar tests, but no one would venture to predict, from any one of these tests, that temperature below which a ship would be unsafe in service. It has already been stated that notched-bar tests may be expected to give a general idea of metallurgical condition and it should now be emphasized that this indication may not be very clear because of the effect of cold work during the tests.

All the steels tested for crack-arresting properties have also been tested in Lehigh, Tipper, and Izod notched-bar tests. The criteria from which assessments are made vary with the tests, but all have been

Table II

COMPARISION OF CRACK TESTS WITH NOTCHED-BAR TESTS

Plate	Ductile Arrest Temp., °C.	Appearance					
		Tipper °C. to °C.		Lehigh °C. to °C.		Izod °C to °C.	
MSZ	30	−10	55	5	50	−20	65
NX	23	−15	45	0	20	−50	30
MSY	20	10	75	5	50	−25	45
WY	20	15	80	40	75	−30	45
MSX	17	10	60	−25	50	−30	35
UX	12	20	75	15	70	−50	50
WV	10	10	60	23	26	−40	25
NY	6	−15	40	− 5	20	−40	25
WZ	2	25	65	10	65	−40	50
UY	0	− 5	50	5	30	−35	40
UR	0	10	50	5	50	−40	50
NZ	0	−15	38	−20	50	−40	50
WX	0	10	50	40	50	−45	60
MSK	12	−10	40	−20	15	−35	35
WN	9	20	60	25	70	−20	50
MSL	6	0	30	10	30	−20	40
MSM	6	−20	40	−50	20	−35	35
NK	0	−50	20	−10	0	−55	0
NM	− 2	−30	5	−20	5	−55	25
NL	− 5	−20	30	2	2	−35	30
WK	−11	−20	40	0	25	−55	50
UK	−20	−20	40	−20	50	−55	30
UG	−25			−25	−10	−45	15
UL	−25	−65	−25	−75	−50	−70	−40
WL	−35	−15	5	−20	10	−55	0
MSD	−28	−40	−10	−25	5	−40	30
UD	−30	−52	−42	−50	−40	−70	−10
ND	−32	−40	−15	−55	−50	−60	−10
WD	−50	0	20	−18	20	−40	30

assessed on appearance of fracture. This assessment is easy to make, it does not admit of much controversy, and it is as consistent in its results as any other. The results of these tests are given in Table II, alongside the ductile arrest temperature for all plates tested and reported in this paper. The discovery of double transitions in notched-bar tests on some steels has lately focused some more attention on the lower-temperature end of the curves. The bottom end of the appearance curve does not present any great difficulty in assessment, so a comparison has also been made for this as well as for the top. In all except the lower transition temperatures for Izod tests, the random nature of the results establishes that no correlation whatsoever exists (Figs. 18*a* and *b*). In the Izod lower-temperature plots for the 40-lb. plates correlation is good until the lower transition temperature reaches − 50° C. For the 25-lb. plates there is a tendency to correlation in the lower-temperature Izod results, but scatter appears at − 35° C. This scatter is to the left. In the 40-lb. plates the Izod figures are 50° C. lower than the ductile arrests and it is only when the materials are tougher by notched-bar standards that the crack-arresting properties do not follow the Izod results. If the tendency for correlation is used as a criterion in the 25-lb. plates, it appears that the Izod figure is only about 20° C. below the ductility arrest. But this 30° C. difference is just that which has been established for thickness effect between these two poundages, so it is evident, of course, that there is little or no thickness effect shown by the lower Izod transition.

The significance of the lower Izod points which did not follow the correlation line has a possible explanation in the results of some experiments made on test pieces that carried no transverse stress and were tested with uniform temperature along their length. The test pieces were coated with ice from a liquid with melting point at the desired temperature of test by immersion in a bath of the fluid after cooling to a much lower temperature. This procedure enabled the test piece to be held at the desired temperature for quite 5 min. while the ice melted. The bolt gun was used to start a crack which ran some 2 in. into the length of the test piece. Cracks could not be started in material *NX* at − 20° C., even though the heaviest charges were used in the bolt gun. Similarly, it was not possible to start cracks reliably in 25-lb. plates *NK* and *NM*, although they could easily be started at − 20° C. in plates *WN* and *MSK* by the light charge used in the full test. Thus, the Izod lower temperature provides a measure of the resistance to crack starting under conditions of very little yield, and in brittle materials this may be related to the crack-arresting temperature.

The crack tests show clearly that the ductile arrest temperatures in the less brittle materials exceed the lower Izod or crack-starting temperatures by a considerable amount. This difference is more apparent in the thinner plates, even though the level of the crack-arresting temperature has fallen. The additional

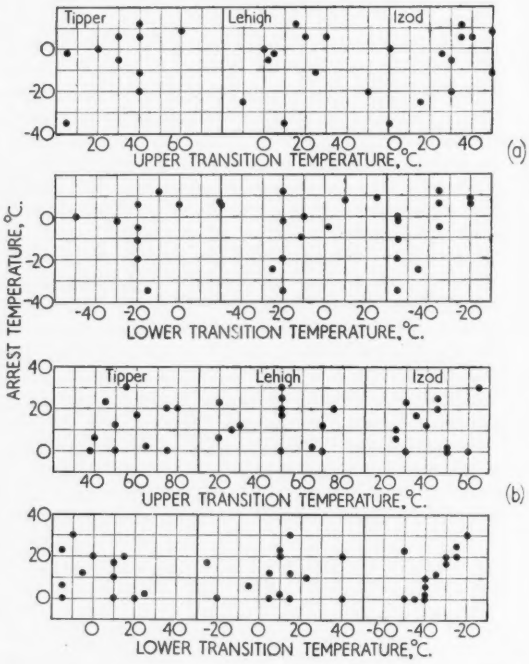

Fig. 18—Comparison between ductile-arrest and notched-bar transition temperatures for: (*a*) 25-lb. plates, (*b*) 40-lb. plates

hot work in the mill may account for this. In materials that exhibit good resistance to crack starting it does not follow that the crack-stopping properties will also be good.

Energy measurements in the Izod test for transverse tests on all the materials tested gave 4 ft.lb. very consistently as the energy at the lower transition temperature, and it was only exceptionally that the energy fell below this value. The upper value for normal steels was also very consistent at 50 ft.lb. One notable exception was plate *UL*, which gave very low temperature-transition values in all tests but had a maximum energy absorption of only 35 ft.lb. This ' dirty ' plate exhibited all the properties of thin plates in the crack tests because of its laminated construction, but its real ductility was low.

As the **V**-notch Charpy test is becoming very popular it is worth considering whether correlation is likely at the lower transition temperature in this test. The higher speed of impact with a blow localized directly below the notch results in higher transition temperatures than in the Izod test. Also, the damage to the material resulting from the blow makes determination of the amount of crystalline appearance somewhat more difficult. (This is perhaps where the Schnadt test, with its elimination of compressive yield, may gain in discriminatory powers.) However, if the temperature relation between crack starting and crack stopping in a material requires low temperatures of the order of — 40° C. for discrimination, it is unlikely that the Charpy test will show correlation with the crack-arresting tests. Charpy tests on plate *NZ* have been made and, as shown in Fig. 19, the results give a normal curve which shows low energy values with small discriminatory effect below — 30° C. The Izod curve, which has been verified by two further series of tests, falls suddenly at about — 40° C., and it is thought that at this temperature the material exhibits a change of some sort—possibly of the kind that shapes one of the wards in the key to the solution of the brittleness problem. That there is a fall in crack-arresting strength in the vicinity of — 40° C. in this material is also shown in Fig. 15, and this is regarded as significant. The significance of this result is that if any brittleness test produces fractures at a series of temperatures and strains different from those that obtain in practice, there is a grave danger that inferences from these tests either may be misleading or may fail altogether to reveal some important change which takes place in practice.

A series of Charpy tests on all the materials reported in this paper is at present in hand, but it is necessary to call a halt in the course of any investigation so that it may be reported, and the elucidation of the question of general correlation with the Charpy test must regretfully be held over and this account of many experiments closed at this stage.

CONCLUSIONS

A new test which evaluates the crack-arresting properties in terms of the temperature and nominal stress in a plate has been developed. The results give critical stress values which are of the order of those observed in cases of catastrophic failure. The ductile

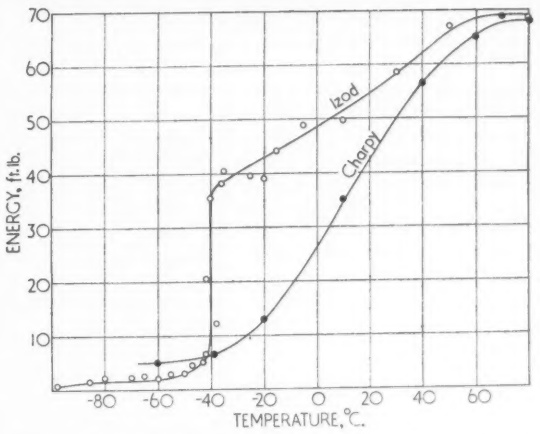

Fig. 19—Izod and Charpy V-notch temperature against energy for plate *NZ*

arrest temperatures cover the actual ranges of temperature within which catastrophic failures have occurred. The method of test has been subjected to checks that ensure that the interpretation of results does give the actual temperature and stress at which a crack will not propagate in catastrophic fashion. The differences between this test and notched-bar tests have been critically examined and the measures of correlation that have been revealed have been explained.

FURTHER WORK

During the course of experiments and development many phenomena have been observed. The actual speed of crack propagation has not been measured with certainty. Two possible ways of measuring this speed show promise. The first would use test pieces at uniform temperature where a crack propagates right through the piece. Under these conditions, provided that a crack exhibits the same degree of surface yield along its length, it may be reasonable to expect that by stopping and starting a counting device by the same event at two different stations the time interval may give a real measure of the speed of the crack. Now that propagation has been allied to a stress, it is hoped that the mechanics of propagation in terms of the actual forces causing separation can be separated from the superabundant available stored energy which at present clouds this important issue in a fog of plasticity and strain. To this end a special test piece has been devised and sufficiently encouraging results have been obtained to give hopes that some fundamental information may be gleaned. It is proposed to carry out tests on larger test pieces at constant temperature to bracket, for different qualities of mild steel, the actual temperature for propagation at working stress values. At present a test piece 3 ft. wide is aimed at.

The question of a simplified test has occupied much time and effort. The present position of ordinary structural steels is that the critical stress is well below the working stresses which designers would be content to accept in steel, so that determination of the upper

arrest temperature may be all-important. This determination gives no difficulty in a simplified test piece (Fig 3.) with a temperature gradient along its length. By applying a blow of much greater severity and increasing the duration of the impulse, a crack can be propagated which will stop at the ductile arrest temperature. If, on the other hand—and here the metallurgist can certainly help—steels can be improved so much that the critical stress value can be raised above the working stress value, then a much more exact test will be necessary. For this test there will be no short cut. If a stress value has to be determined, then loading will have to be applied so that its distribution within the test piece is known. This can mean no less work than the minimum required for the full crack test.

Acknowledgments

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The Density of Molten Iron

By V. H. Stott, D.Sc., and J. H. Rendall, B.Sc.

SYNOPSIS

Two closely agreeing measurements of the density of molten iron (averaging 7·00 g./c.c. at 1564° C.) have been made by filling *in vacuo* a pyknometer made of alumina and determining the mass of iron contained in it. The experiments were, however, difficult to perform because the H.F. induction furnace imposed serious temperature gradients on the alumina. Further work should be carried out with the aid of a furnace designed specially for the measurements to be undertaken.

Estimates of the shrinkage on solidification and of the coefficient of expansion of the liquid metal have been made using formulæ put forward by Kubaschewski. 807

In spite of the importance of iron, comparatively few measurements have been made of its physical properties in the liquid state, and the accuracy of such measurements is not easy to estimate. Determinations of the density have been made by Benedicks and his collaborators,[1–3] and by Desch and Smith.[4] The former measured the difference in level of molten iron in two limbs of a **U**-tube, together with the corresponding difference of pressure. The formation of bubbles of gas in one or both limbs of the **U**-tube was a source of considerable errors. Desch and Smith measured the buoyancy of a cylinder of alumina immersed in the melt. No correction appears to have been made for the additional force produced by the surface tension of the liquid acting on the relatively thick stem which served to immerse the cylinder of alumina. It may have been supposed that calibration of the apparatus with mercury eliminated this error, but for this to have occurred it would have been necessary for the ratio of the vertical forces due to surface tension to have been equal to the ratio of the densities of the liquids, the latter ratio being the same as that of the forces of buoyancy. The vertical force due to surface tension cannot be calculated without knowledge of the angle of contact between liquid and solid, but it is known that the ratio of surface tensions is about three, whereas that of the densities is about one-half. The diameter of the stem and the volume of the sinker can be estimated from Desch and Smith's Fig. 34 (*loc. cit.*,[4] p. 361), and if in each case the angle of contact is assumed to be about the same as that of mercury and glass in air, it seems that an error of about 4% in the measured density may have resulted from the effects of surface tension, the measured density being raised by this error. Bubbles attached to the cylinder could have caused errors in the opposite sense.

The presence in the Metallurgy Division of the N.P.L. of a H.F. furnace, in which 25-lb. batches of iron could be melted in a controlled atmosphere or *in vacuo*, permitted new measurements of the density of molten iron to be made by means of a pyknometer, which could be filled *in vacuo* by immersion in the melt. The chief disadvantage of this simple method was the difficulty of inserting the pyknometer without cracking it, a difficulty inherent in the melting apparatus, which had not been designed for the purpose of these experiments. Two determinations of density have been made, and are in good agreement, but in each case the alumina pyknometer cracked, fortunately in such a way as not to interfere with the measurement. Further work should be carried out in a furnace so designed that the pyknometer and the metal can be heated slowly at the same time, thus reducing the risk of cracking the pyknometer. Meanwhile, the above experiments appear to merit description, in view of the paucity of reliable data about the physical properties of molten iron.

METHOD OF MEASUREMENT

Figure 1 represents a section through the axis of the cylindrical pyknometer. The material used

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Dr. Stott and Mr. Rendall are in the Metallurgy Division of the National Physical Laboratory.

consisted of four parts of fused alumina, which had been crushed and passed through a sieve having 90 meshes to the inch, and one part of much finer alumina to act as a binder. The cavity was made with a tapered opening at the bottom, to be sealed later with a tapered plug. The pyknometer and the plug were fired to 1250° C. and the two parts were then gently ground together. Both parts were washed and soaked with water, and the plug was lightly painted with an aqueous suspension of very fine alumina, and twisted into position. Finally, the pyknometer was fired in a kiln to 1700° C. During the subsequent experiments no iron penetrated these joints.

The melting apparatus has been described in detail by Hopkins, Jenkins, and Stone.[5] The iron was heated by means of induced H.F. electric currents. It was contained in an alumina crucible, and the furnace and its accessories were surrounded by a large steel cylinder which could be evacuated, or filled with a desired gas. Manipulations could be carried out within the cylinder by means of steel rods passing from the outside through Wilson seals, and these rods were free to move longitudinally and to rotate about their geometrical axes. By suitable attachments to such rods, objects within the cylinder could be moved as required. In particular, a steel clamp lined with asbestos cloth held the pyknometer at the narrow part of its upper end, and this clamp was rigidly attached by a short horizontal strip of steel to the bottom of one of the rods passing through a Wilson seal. Hence, by twisting the rod, the pyknometer could be moved from an initial position above and to one side of the crucible to a position on the axis of the crucible, and then it could be lowered vertically. These movements were performed in small steps over a long time in the hope of not cracking the alumina pyknometer which, when not partially immersed in the molten iron, was heated almost entirely by radiation from the metal. The large steel container was evacuated before lowering began, and when the pyknometer was well immersed in the molten iron, the head of liquid was enough to overcome the forces due to surface tension at the mouth of the capillary entrance to the cavity of the pyknometer, which then filled with liquid. The temperature of the iron was measured with a quick-immersion thermocouple. The stirring of the melt that occurred as a result of the heavy currents flowing through it was so vigorous that the variations of temperature within the melt were found to be negligible. Ample time was allowed for the establishment of equality of the temperatures of the iron inside and outside the pyknometer, which was then withdrawn.

To determine the density at the measured temperature, it was necessary to know, at this temperature, the volume of the cavity in the pyknometer, and the mass of the iron which filled it. The volume could be measured at room temperatures by means of mercury, filling being done in the same apparatus as that used for iron. Duplicate determinations on the first pyknometer differed by 1 part in 7000. The second pyknometer was calibrated with mercury only once, but the weighings were checked by a second observer. The capacity of the pyknometer at the working temperature was calculated from knowledge of the thermal expansion of alumina, and is discussed on p. 376. However, the question arose of whether any permanent change of volume could have been produced as a result of the heat-treatment of the alumina. Consequently, after the first experiment on iron, a 2-in. length was cut from the top end of the pyknometer, which had been only slightly heated during the experiment. The ends of this specimen were ground flat and parallel, and the distance between them was measured. The specimen was then heated in 5 hr. to 1600° C., a temperature that was maintained for another hour. After the specimen had cooled, it was again measured, and was found to be shorter by 8 parts in 100,000. The change of volume was therefore about 1 part in 4000. The pyknometers were never heated to as much as 1600° C. during the measurements of density, and they were not at their highest temperatures for as long as 1 hr. The dimensional stability of the alumina appears, therefore, to have been adequate.

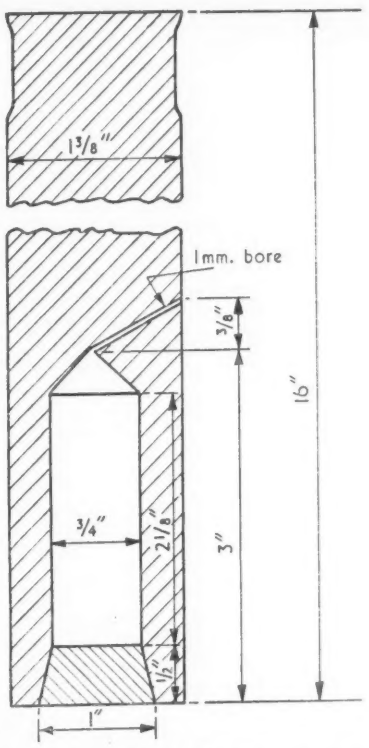

Fig. 1—Section through axis of cylindrical pyknometer. All dimensions are approximate

It was not difficult to determine the mass of iron which filled a pyknometer. By gentle tapping with a hammer the alumina could be broken and the ingot exposed. Particles of alumina were embedded in its surface. In this state the ingot was weighed. It was then treated with hydrochloric acid, which etched the surface and released the alumina. This was washed and dried, and by subtracting its weight from the weight of the ingot in its original state, the weight of the iron was found. As a check, the etched ingot was washed quickly with water, alcohol, and ether,

successively, and then dried and weighed. The iron that had been dissolved was determined chemically and added to this weight. In the first experiment the etched iron was slightly rusty in spite of the method of washing and drying. The weights obtained by the two methods were 109·24 and 109·25 g., respectively. Corresponding weights for the second determination of density were 110·87 and 110·86 g., the pyknometers being, of course, different.

In the first determination the lowering of the pyknometer took about 1 hr., and in its final position the capillary entrance was about 2 in. below the surface of the melt. The pressure of gas was 0·21 mm. of Hg, the atmosphere before evacuation having been hydrogen. The pyknometer was completely immersed for about 1 hr., during which time the temperature of the bath dropped 31° C., but the drop during the last 25 min. was only 5° C. The pyknometer was quickly raised clear of the melt, and the effective temperature of filling was taken as that read just before raising. During the second determination there was a rise of temperature of 4° C. in the last 16 min.

In each case the pyknometer cracked above the capillary entrance, and in the first experiment the end of the pyknometer broke off and was left floating in the melt at an angle of about 45°, the top of the broken part being in contact with the rest of the pyknometer, and the capillary entrance being fortunately uppermost. In the second experiment the end of the pyknometer remained in position in spite of a crack above the capillary entrance. In the first experiment the iron in the pyknometer cooled asymmetrically, and a piece of wire-like iron, corresponding with the capillary entrance, was attached to the upper point of the ingot. The shrinkage cavity was a little to one side of this. The symmetrical conditions of the second experiment produced an axial shrinkage cavity, and the metal in the capillary entrance had been drawn into the main part as a result of cooling of this part before the occurrence of solidification in the capillary entrance.

After corrections had been made for the expansion of alumina and for the presence of impurities, the results of the measurements were: first determination $7{\cdot}00_9$ g./c.c. at 1569° C., second determination $6{\cdot}99_8$ g./c.c. at 1559° C.; or, taking averages of both densities and temperatures, 7·00 g./c.c. at 1564° C. The discrepancy between the determinations cannot be specified without knowledge of the coefficient of expansion of the molten metal. Present knowledge[9] (*see* p. 378) indicates that the values of the density, after reduction to a common temperature, agree to within two units in the second decimal place.

DISCUSSION

Corrections for Sources of Error

Expansion of Alumina—The corrections for the expansion of alumina exceeded 4%, and were calculated from a table obtained by smoothing the results of Ebert and Tingwaldt,[6] who published figures for temperatures ranging from 0° to 1800° C. Their values were compared with those of Merritt,[7] who worked within a smaller range of temperatures. For the range 25–800° C., the ratio of the expansion according to Ebert and Tingwaldt to the expansion according to Merritt is 1·016. Ebert and Tingwaldt used 'sinterkorund,' which probably contained more than 99·5% of alumina, Merritt's material contained 99·9% of alumina, and the material used in the present investigation contained about 99·7%. Assuming from the above an uncertainty of 2% in the expansion of alumina, the corresponding uncertainty in the present authors' measurements of density is about half a unit in the second decimal place. For commercial fused alumina, fired twice to 1800° C., a value for the expansion from 20° to 1750° C. has been published by the Bureau of Standards.[8] This value is 6·1% less than that obtained from the measurements of Ebert and Tingwaldt, and its use in the present calculations would raise the value of the density of iron by two units in the second decimal place. It should be remembered, however, that little is known about the influence of impurities on the expansion of alumina.

Impurities in Iron—The measurements of density were made on specially purified iron, and the impurities in the residual material were determined. The source of iron for the first experiment was the firm of Krupp, and the iron for the second experiment was of Japanese origin. The analyses were:

	Krupp Iron, %		Japanese Iron, %
C	0·0038		0·0026
Si	<0·001		0·007
S	0·011		0·010
P	0·002		0·001
Mn	<0·005		<0·005
Ni	0·062		0·005
Cr	0·005		0·003
Cu	0·018		0·003
Mo	<0·005		...
Al	<0·001		0·002
As	0·03		<0·002
O_2	0·042	Determined on metal from the pyknometer	0·048
H_2	0·0006		0·0008
N_2	0·008		0·004

The effects on the density, of carbon, silicon, phosphorus, manganese, nickel, chromium, and aluminium, could be calculated from the published measurements of Benedicks, Ericsson, and Ericson.[3] The approximate effects of sulphur, oxygen, and nitrogen were calculated by assuming the formation of FeS, FeO, and Fe_2N, assuming additive volumes in the solid state, and further assuming that the relative effect is independent of temperature. Similar assumptions were made in connection with copper, molybdenum, and arsenic, except that the specific volumes of the elements themselves, and not those of compounds, were used for the calculations. Benedicks, Ericsson, and Ericson have shown that in most cases such assumptions yield fairly good results, and in the present instance large errors could be tolerated, because the effects of the impurities (other than hydrogen) were to lower the measured densities by only about 0·008 for the Krupp iron and by about 0·009 for the Japanese iron. No correction has been made for the presence of hydrogen. The density of liquid hydrogen is about 0·07. Assuming additive volumes in the liquid states, and ignoring temperature, the corrections for the Krupp iron and for the Japanese iron are about 0·004 and 0·006, respectively. It is probable, how-

ever, that the volumes are far from additive, and that the presence of hydrogen has little influence on the volume of liquid iron. If this is true, the corrections are quite negligible.

Metal Penetration and Filling of Pyknometer—The pyknometer was porous and did not offer great resistance to the passage of gas through it, for, after calibrating with mercury, the metal could be poured out readily through the opening of only 1 mm. dia. (the last traces of mercury were removed by heating to about 900° C.). It may be asked, therefore, whether liquid metal can penetrate the pores. The largest particles in the raw fused alumina pass through a sieve of 90 meshes to the inch. The opening of an I.M.M. sieve of this kind is a square of 0·14 mm. side. If all the particles were of this size, the pores would be smaller, but since ' fines ' are present and a still finer alumina is used as a binder, the pores are indeed much smaller. One-fifth of an atmosphere is needed to force mercury into a circular hole of about 0·1 mm. dia., and the highest pressure available in the present case was less than $\frac{1}{5}$ atm. Mercury was therefore not forced into the normal pores of the material. As, however, the pyknometer was ' slip-cast,' it contained a few bubbles that were much larger than the normal pores, and these were filled by metal, for the iron ingots, after removal of the alumina by etching, showed corresponding spherules on the surface. The depth of etching was only about 0·04 mm. for the first experiment, and less for the second.

Another matter of interest is how closely the metal fits an angle such as that between the cylindrical wall of the cavity and its base. Let P represent the pressure of mercury in dynes/sq. cm., let T be the surface tension in dynes/cm., and let R_1 and R_2 be the principal radii of curvature of the surface. Then

$$P = T\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \quad \ldots\ldots(1)$$

At a depth of 15 cm., $P = 15(13{\cdot}5)(981)$ dynes/sq. cm., or about 200,000 dynes/sq. cm., T is roughly 500 dynes/cm., and, since the diameter of the cylindrical cavity is about 2 cm., R_1 is approximately equal to 1.

Hence, from equation (1),

$$200{,}000 = 500\left(1 + \frac{1}{R_2}\right) \quad \ldots\ldots(2)$$

and R_2 is roughly 1/400 cm. The volume not occupied by mercury is therefore that swept out by the revolution, at a radius of 1 cm., of a surface bounded by a vertical straight line 1/400 cm. long, by a horizontal straight line 1/400 cm. long, and by an arc of radius 1/400 cm. completing a triangle with a curved hypotenuse. A larger volume is obtained if the curve is replaced by its chord; the surface then becomes that of a right-angled triangle with equal sides of 1/400 cm. including the right-angle. The area of this triangle is 1/320,000 sq. cm. The corresponding swept volume is $2\pi/320{,}000$ or about 1/50,000 c.c. The volume of the cavity is about 15 c.c., so that the filling error at the bottom edge is less than 100/15 (50,000) %, or 1/7000%. The density of molten iron is about half that of mercury, and the surface tension is about three times that of mercury, so that the error in the case of iron is less than about $\frac{1}{2000}$%. Errors of this kind are therefore negligible. It has been shown that neither metal can penetrate the normal pores of the refractory, and that each metal sufficiently follows the contour of the cavity. There might, however, be bubbles in the refractory which could be entered by mercury, but not by iron. In theory the ratio of the diameters of the smallest bubbles, similarly cut by the surface, entered by the two metals, respectively, is about 1/6. In practice slight chemical action between the iron and the refractory may reduce this ratio, a suggestion which seems to be supported by the existence of roughly spherical excrescences on the ingots, having diameters which may be as little as 0·15 mm. The spherules of all sizes seem to be spaced on the average more than 1 mm. apart, and only some of those smaller than 0·15 mm. are likely to be entered by one metal and not by the other. The volume of a set of complete 0·15-mm. dia. spherules at the corners of a square mesh of 1 mm. side, and having a total area equal to that of the surface of the ingot, is only about $\frac{1}{70}$% of the volume of the cavity. The actual excrescences have, in general, the form of part of a sphere. It is unlikely, therefore, that the presence of bubbles in the refractory is an important source of error. The bubbles were originally present in the ' slip ' or slurry from which the refractory was ' cast ' in a plaster mould. By vacuum-treatment of the slip the bubbles can be almost eliminated, and this precaution could be taken in future work.

Comparison with Earlier Measurements

In comparing measurements made at different times it has been necessary to take into account small changes in the International Scale of Temperature. The present authors' value for the density (7·00 g./c.c.) refers to a temperature of 1564° C. in accordance with the present scale. For the same temperature Benedicks, Ericsson, and Ericson[3] found 7·18 g./c.c., and the series of measurements from which this value was deduced is far more extensive than earlier measurements with which Benedicks was associated. Moreover, there are difficulties in the interpretation and adjustment of this earlier work to allow for differences of temperature and composition, and in drawing a density/temperature curve through points which appear to be somewhat erratic. There can be no doubt, however, that all the work with which Benedicks was associated leads to a higher value for the density at 1564° C. than that found in the present investigation.

Desch and Smith[4] obtained a mean value of 6·965 g./c.c. at 1544° C., but the iron used contained an average amount of 0·38% of carbon. The measurements of Benedicks, Ericsson, and Ericson[3] enable a correction to be made for the presence of carbon, and the corrected value is 7·01 g./c.c. Allowing for the difference of temperature, this value is less than that of the present authors by 0·01 if the temperature coefficient obtained by Benedicks is accepted, and it is the same as that of the present authors if a coefficient based on a calculation referred to on p. 378 is used. The work of Desch and Smith[4] may, however, contain an error resulting from effects of

surface tension, and allowance for this error may lower the density to 6·7 g./c.c. The discrepancy between values falling on each side of the present authors' figure is considerable, and the importance of iron would justify further measurements.

Variation of Density with Change of Temperature

According to Benedicks, Ericsson, and Ericson,[3] who measured the density of molten iron over a range exceeding 200° C., a rise of temperature of 100° C. lowers the density by 0·1, the coefficient of volumetric expansion being therefore 14×10^{-5}. Berlin[2] found a higher rate of change of density, particularly at the lower temperatures, but the effects of experimental errors in the determination of density are relatively much greater in the case of the temperature coefficient. A rough value for the coefficient of volumetric expansion α of a molten cubic metal, of high co-ordination number, at a temperature just above its melting point T_m (in ° K.), can be calculated from the following formula given by Kubaschewski:[9]

$$\alpha = C_p/75\ T_m \qquad (3)$$

where C_p represents the atomic heat of the molten metal at its melting point. The value of α, derived from the formula, is 7×10^{-5}, which is only half that of Benedicks, Ericsson, and Ericson. As mentioned above, that of Berlin[2] is still higher. Kubaschewski's formula is largely empirical, and, owing to lack of data about expansions, it is based on the physical constants of metals of lower melting points than that of iron. An analogous formula yields the coefficient of expansion of a solid cubic metal at a temperature just below its melting point. The value obtained for platinum in this way is about one-fifth higher than that obtained by extrapolating the direct measurements of Holborn and Day.[10] The value of α obtained from Kubaschewski's formula for the case of molten iron is probably less in error than the values resulting from direct experiment.

Change of Volume on Solidification

The change of volume of a substance during melting or freezing is of interest because of its connection with the rate of change of melting point with respect to change of pressure. It is known that

$$\frac{dT}{dp} = \frac{(v_l - v_s)}{L_f} T \qquad (4)$$

where T is the absolute melting point at the pressure p, v_l is the specific volume of the liquid, v_s is that of the solid, and L_f is the latent heat of fusion expressed in terms of the same unit of energy as that of the quantity $p(v_l - v_s)$. Of the quantities $v_l - v_s$, T, and L_f, the first is by far the most uncertain. Its value is not likely to be much more than 3% of that of v_l, so that to obtain it from the separate values of v_l and v_s the latter must be determined very accurately. It is of interest, nevertheless, to see what values are obtained from the experimental results available. It will be convenient to calculate the value of $(v_l - v_s)/v_l$, or, since densities are reciprocals of specific volumes, of $(\rho_s - \rho_l)/\rho_s$, in which ρ_s and ρ_l represent the densities of the solid and of the liquid, respectively.

The density of δ-iron at 1425° C. (old scale) was determined by X-ray diffraction by Westgren and Phragmén[11] to be 7·32. The coefficient of volumetric expansion was found by Schmidt,[12] from X-ray diffraction, to be $5{\cdot}85 \times 10^{-5}$. Kubaschewski's formula gives $6{\cdot}4 \times 10^{-5}$. The value 6×10^{-5} may therefore be used to calculate the density at the melting point; this gives 7·273. The present authors' value for the density of liquid iron at 1564° C. is 7·003. Hence, at 1532° C., which was taken as the melting point on the present international scale, the value becomes 7·019 if the value of 7×10^{-5}, given by Kubaschewski's formula, is accepted as the coefficient of volumetric expansion of molten iron. From the above figures $(v_l - v_s)/v_l$ is 3·5%, but becomes 3·4% if the value given by Benedicks, Ericsson, and Ericson[3] for the coefficient of expansion is used. These authors have, however, found 7·23 for the density of molten iron at the melting point, and if this value is used, $(v_l - v_s)/v_l$ is equal to 0·6%.

A direct determination by Ericson[13] of the shrinkage on solidification of iron yielded the value 2·34% (the published value was 2·4%, but this was in terms of the volume of solid iron, whereas the present authors' value refers to that of liquid iron). The value given by Ericson may be subject to considerable error as a result of difficulties both of experiment and of interpretation.

According to Kubaschewski[9] the change in volume on solidification is proportional to the change of entropy. Taking the atomic heat of fusion[14] as 3·63 kg.cal., the value of $(v_l - v_s)/v_l$, calculated from his formula, is 2·9%.

Acknowledgment

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References

1. C. Benedicks, D. W. Berlin, and G. Phragmén: *Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1924, vol. 13, pp. 129–174.
2. D. W. Berlin: *Ibid.*, 1926, vol. 15, pp. 1–15.
3. C. Benedicks, N. Ericsson, and G. Ericson: *Arch. Eisenhüttenwesen*, 1930, vol. 3, pp. 473–486.
4. C. H. Desch and B. S. Smith: *J. Iron Steel Inst.*, 1929, No. I, pp. 358–363.
5. B. E. Hopkins, G. C. H. Jenkins, and H. E. N. Stone: *Ibid.*, 1951, vol. 168, pp. 377–383.
6. H. Ebert and C. Tingwaldt: *Physikalische Zeitschrift*, 1936, vol. 37, pp. 471–475.
7. G. E. Merritt: *Transactions of the American Electrochemical Society*, 1926, vol. 50, pp. 165–173.
8. *Technical News Bulletin of the National Bureau of Standards*, 1930, No. 158, pp. 55–56.
9. O. Kubaschewski: *Trans. Faraday Soc.*, 1949, vol. 45, pp. 931–940.
10. L. Holborn and A. L. Day: *American Journal of Science*, 1901, vol. 11, pp. 374–390.
11. A. Westgren and G. Phragmén: *J. Iron Steel Inst.*, 1922, vol. 105, pp. 241–262.
12. W. Schmidt: *Ergebnisse der technischen Röntgenkunde*, 1933, vol. 3, pp. 194–201.
13. G. Ericson: *Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1934, vol. 23, pp. 13–45.
14. O. Kubaschewski: *Zeitschrift für Elektrochemie und angewandte physikalische Chemie*, 1950, vol. 54, pp. 275–288.

HISTORICAL NOTE No. 32

Campaign and Output of the Furnace at Rievaulx, in Yorkshire, in 1591-92

By Dr. H. R. Schubert

DETAILED accounts of sixteenth-century ironworks are rare. Professor L. Beck, in his voluminous "History of Iron," directed attention to quarterly accounts from 1573 to 1590 concerned with a furnace and forge called Teichütte at Gittelde, in the Harz Mountains of North Germany, emphasizing that there are no other accounts existing which are of a similar minuteness of detail.[1] It was not known in his days that in England we have equally detailed accounts of the same period and even earlier; *e.g.*, accounts concerned with the furnaces of Robertsbridge and Panningridge, in Sussex, beginning with 1541.[2] Of a somewhat later date, *i.e.*, starting with 1577–78, are the accounts of furnace and forge at Rievaulx in Yorkshire, which belonged to the Earls of Rutland in the 16th and 17th centuries.[3] Amongst them there is an account, of 1591–92, which contains a detailed list of the furnace output during a whole campaign, which started on 19th October, 1591, and ended on 23rd April, 1592.[4] Such detailed accounts of production are very rare, and this is probably the earliest existing in the world. For this reason it seems justifiable to publish it in full, as follows:

Date		sows and pigs:	weight[5]	cast ware:	weight	total weight
October	23	*one sow:*	11*c.*			
	24		9*c.* 2 *sto.*			
	25		11*c.*			
	26		12*c.* 6 *sto.*			
	27	1 *bronsen*[6] *sow*	11*c.* 6 *sto.*			4 *ton* 16*c.* 2 *sto.*
	28		13*c.* 6 *sto.*			
	29	[2 *sows*]	13*c.* 4 *sto.* 13*c.* 2 *sto.*			
	30		—			
	31		16*c.* 2 *sto.* 15*c.* 4 *sto.*			
November	1		17*c.* 4 *sto.*			
	2		15*c.* 6 *sto.* 15*c.*			
	3		16*c.*			
	4		15*c.*			
	5		14*c.*			
	6		16*c.* 6 *sto.*			
	7		16*c.* 2 *sto.* 16*c.* 6 *sto.*			13 *to.* 18*c.*
	8		14*c.* 6 *sto.* 15*c.*			
	9		13*c.* 2 *sto.*			
	10		13*c.* 2 *sto.*			
	11		16*c.* 2 *sto.* 15*c.*			
	12		15*c.* 6 *sto.*			
	13		15*c.*			
	14		16*c.*			
	15		16*c.* 4 *sto.*			
	16		15*c.* 2 *sto.*			
	17		15*c.*			
	18		15*c.* 15*c.* 6 *sto.*			
	19		14*c.* 4 *sto.* 17*c.* 2 *sto.*			14 *to.* 14*c.* 2 *sto.*
	20		17*c.* 2 *sto.*			
	21		14*c.* 4 *sto.*			
	22		16*c.* 16*c.*			
	23		17*c.* 6 *sto.*			
	24		18*c.* 2 *sto.*			
	25		18*c.*			
	26		17*c.* 4 *sto.* 18*c.* 6 *sto.*			
	27		19*c.* 4 *sto.*			
	28		19*c.* 6 *sto.*			
	29		17*c.* 4 *sto.*			
	30		19*c.* 6 *sto.* 19*c.* 4 *sto.*[7]			
December	1		19*c.* 2 *sto.*			
	2		18*c.* 4 *sto.*			
	3		17*c.* 4 *sto.* 16*c.* 4 *sto.*			16 *to.* 2*c.*
	4		19*c.*			
	5		19*c.* 6 *sto.*			
	6		18*c.* 4 *sto.*			
	7		19*c.* 6 *sto.*			
	8		19*c.*			
	9		19*c.* 4 *sto.*			
	10		19*c.* 17*c.* 4 *sto.*	2 *hurstes*	2*c.* 4 *sto.*	
	11		16*c.*	2 *plaites for puttinge in the bottom of the fyneris weinge*	4*c.*	
	12		15*c.*	2 *plaites for the same use:*	4*c.*	
	13		20*c.*			
	14		19*c.* 2 *sto.*			
	15		14*c.* 2 *sto.*	2 *plaites for the fineries:*	4*c.* 6 *sto.*	
	16		14*c.* 4 *sto.*	2 *plaites for the same use:*	5*c.* 4 *sto.*	16 *to.* 8*c.*
	17		19*c.* 6 *sto.*			
	18		19*c.* 2 *sto.*			
	19		12*c.* 2 *sto.*	2 *plaites for the like use:*	6*c.* 2 *sto.*	
	20		20*c.*			
	21		19*c.* 6 *sto.*			
	22		18*c.* 6 *sto.*			
	23		19*c.* 6 *sto.* 19*c.*			
	24		19*c.*			
	25		18*c.* 2 *sto.*			
	26		18*c.* 2 *sto.* 18*c.* 2 *sto.*			
	27		19*c.* 2 *sto.*			
	28		19*c.* 3 *sto.* 18*c.* 4 *sto.*			
	29		18*c.* 4 *sto.*			
	30		18*c.* 6 *sto.*			
	31		19*c.* 4 *sto.* 19*c.* 4 *sto.*			16 *t.* 3*c.* 4 *sto.*
January	1		18*c.*			
	2		16*c.* 2 *sto.*			
	3		18*c.* 6 *sto.* 19*c.* 2 *sto.*			
	4		11*c.*			
	5		11*c.* 4 *sto.*			
	6		15*c.* 6 *sto.*			
	7		11*c.* 6 *sto.* 11*c.* 6 *sto.*	3 *anvels:* 2 *hammers:*	15*c.* 6 *st.* 8*c.* 6 *sto.*	

[1] L. Beck, "Geschichte des Eisens," vol. II, p. 786; 1893–1895, Braunschweig, Druck und Verlag von Freidrich Vieweg und Sohn.

[2] In possession of Lord De L'Isle and Dudley, Penshurst Place, Kent.

[3] Preserved in the Archive of His Grace the Duke of Rutland, Belvoir Castle, Leicestershire.

[4] *Ibid.*, Account Nos. 529 and 530.

[5] The weights were 1 ton = 20 cwt., 1 cwt. = 8 stones, 1 stone = 14 lb. The difference between a sow and a pig is a difference in weight only, *i.e.*, a sow generally weighing above and a pig below 10 cwt.

[6] Burst, ruptured.

[7] Crossed out in the text.

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Dr. Schubert is Historical Investigator to The Iron and Steel Institute.

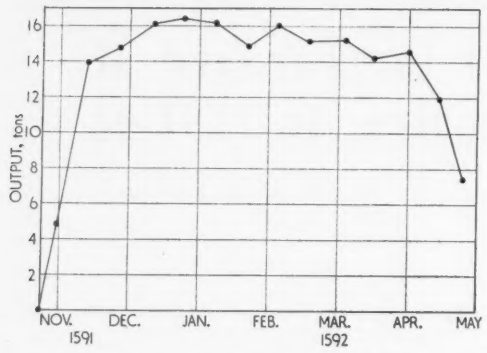


Fig. 1—Graph of furnace output during the campaign at Rievaulx, 1591–92

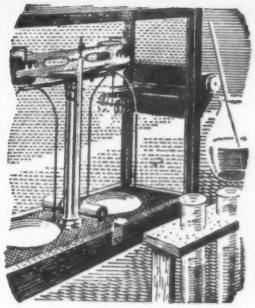
Date		*sows and pigs:*	*weight*	*cast ware:*	*weight*	*total weight*
	8		11c. 6 *sto.*			
	9		10c. 4 *sto.*			
	10		9c. 4 *sto.* 10c. 6 *sto.*			
	11	*one pigge:*	4c.			
	12		19c. 2 *sto.*			
	13		19c.			
	14		18c. 4 *sto.* 19c. 6 *sto.*			14 *to.* 16c. 4 *sto.*
	15		18c. 2 *sto.*			
	16		18c. 2 *sto.*			
	17		18c. 2 *sto.*			
	18		18c. 6 *sto.*			
	19		19c. 4 *sto.*			
	20		20c. 18c. 6 *sto.*			
	21		19c.	1 *anvell:* 4 *hammers:*	5c. 2 *sto.* 17c. 4 *sto.*	
	22		19c. 2 *sto.*			
	23		19c.			
	24		18c. 2 *sto.* 16c.			
	25		18c. 6 *sto.*			
	26		18c. 4 *sto.*			
	27		19c.			
	28		19c. 6 *sto.*			
	29		18c. 6 *sto.*			16 *to.* 6 *sto.*
	30		20c.			
	31		20c. 20c.			
February	1		20c.			
	2		17c. 4 *sto.*			
	3		19c. 2 *sto.* 17c. 4 *sto.*			
	4		19c. 2 *sto.*			
	5		—			
	6		20c.			
	7		19c. 2 *sto.*			
	8		20c.			
	9		20c.			
	10		17c. 6 *sto.* 18c. 2 *sto.*			
	11		19c.			
	12		18c. 4 *sto.*			15 *to.* 2c. 6 *sto.*
	13		20c. 18c.			
	14		20c.			
	15		18c. 2 *sto.*			
	16		18c. 2 *sto.*			
	17		17c. 2 *sto.*			
	18		18c. 4 *sto.* 19c. 6 *sto.*			
	19		18c.			
	20		20c.			
	21		20c.			
	22		19c. 2 *sto.*			
	23		20c.			
	24		20c.			
	25		17c.			
	26		20c.			
	27		19c. 2 *sto.*			
	28		19c. 2 *sto.*			
	29		16c.	2 *playtes being bottom playtes weing* 2c. *a pece*		15 *to.* 4c. 6 *sto.*
			18c. 2 *sto.*			
March	1		18c. 2 *sto.*	2 *plates the one a bottom playt the other a sid(e) finerie plaite weing bothe*	5c.	
	2		14c. 4 *sto.*	2 *plates:*	5c. 2 *sto.*	
	3		14c. 2 *sto.* 11c. 6 *sto.*	2 *plaites:* 2 *plaites:*	5c. 4c. 4 *sto.*	
	4		17c. 6 *sto.*			
	5		17c. 2 *sto.*			
	6		18c. 2 *sto.*			
	7		15c. 4 *sto.*			
	8		11c. 6 *sto.*	2 *plates:*	6c. 2 *sto.*	
	9		14c. 6 *sto.* 17c. 2 *sto.*	2 *plaites:* 1 *chaiffery plate*	5c. 2 *sto.* 2c. 6 *sto.*	
	10		16c. 6 *sto.*	1 *plate:*	3c.	
	11		12c. 2 *sto.*	1 *other chaiffery playte:*	3c. 4 *sto.*	14 *to.* 3c.
	12		8c.	1 *anvell:* 1 *hurst:*	5c. 2 *sto.* 1c. 2 *sto.*	
	13		18c. 4 *sto.*			
	14		11c.	1 *hammer:*	5c.	
	15		12c. 2 *sto.*	1 *hammer:*	5c.	
	16		13c.	1 *hammer:*	5c.	
	17		18c. 2 *sto.*			
	18		18c. 2 *sto.* 17c. 4 *sto.*			
	19		18c.			
	20		17c. 6 *sto.*			
	21		16c.			
	22		18c. 6 *sto.*			
	23		19c. 2 *sto.* 17c. 6 *sto.*			
	24		19c.			
	25		19c. 6 *sto.*			14 *to.* 11c.
	26		18c. 2 *sto.*			
	27		19c.			
	28		18c. 2 *sto.*			
	29		17c. 6 *sto.*			
	30		17c. 6 *sto.*			
	31		17c. 2 *sto.* 18c. 4 *sto.*			
April	1		18c. 6 *sto.*			
	2		16c. 6 *sto.*			
	3		17c. 4 *sto.*			
	4		16c. 4 *sto.*			
	5		17c.			
	6 *and* 7		—			
	8		18c. 4 *sto.*			11 *to.* 18c. 4 *sto.*
	9		20c.			
	10		20c.			
	11		20c.			
	12		17c. 6 *sto.*			
	13		17c. 6 *sto.*			
	14		20c. 18c.			
	15		19c. 4 *sto.*			
	16		19c.			
	17		19c. 4 *sto.*			
	18		18c. 4 *sto.*			
	19		18c. 4 *sto.*			7 *to.* 8c.
	20	*one pigge:*	9c.	1 *hammer:*	5c.	
	21		18c.			
	22	*one pigge:*	9c.	1 *hammer:*	5c.	
	23	*one pigge:*	7c.			

According to the account, the furnace "*began to blowe the XIX day of October* 1591." This means that the fire was put in at that date, for the first few days it served only for preheating the interior. After this, it still took several days before a quantity of molten iron sufficient for tapping had collected in the hearth. The first tapping took place on the sixth day, on which occasion the founder, Thomas Browne, received an extra allocation of "*ale and bread.*" The output was fairly small at first. The full capacity of 20 cwt. (at one tapping), was not attained before the 13th December. In the last four days before blowing out, the output decreased considerably, which was quite normal as the hearth was then worn out (*see* Fig. 1).

The total amount produced in the campaign, which lasted a few days more than half a year, was 198 tons 15½ cwt.; *i.e.*, 1 ton 1¼ cwt. per 24 hr. Of the total, not more than 7 tons 8¼ cwt. were castings, *i.e.*, 3½%.

Casting began after 7 weeks, on 10th December. Even after this date, it was effected at intervals only. The castings produced were all of a heavy type and were all destined for the equipment of the forge, such as anvils, hammerheads and hursts for the power hammer, and plates for the fireplaces of finery and chafery. The strikingly small ratio of castings to pig iron was completely in keeping with the respective ratios at contemporary furnaces.

The Protection of Iron and Steel by Metallic and Non-Metallic Coatings—II



By J. C. Hudson, D.Sc., F.I.M., and J. F. Stanners, B.Sc.

SYNOPSIS

This is the second report on a series of tests on the protection of structural steel by metallic coatings and by non-metallic coatings other than oil paints, which was begun in 1940. Specimens were exposed in the open air at various sites in the U.K. and overseas, where they have been kept under observation for up to 12 years; rather more than half of them are still under test. Other specimens were immersed in the sea and were finally removed after six years.

The tests have confirmed earlier conclusions that certain metallic coatings give excellent protection to steel exposed to atmospheric corrosion. Zinc and aluminium coatings are most generally useful for heavy structural steel, but good results may also be obtained from lead coatings in industrial atmospheres. Of the metal coatings tested, zinc is the best for protecting steel immersed in sea-water.

Vitreous enamel and thick sprayed coatings of cement–asbestos behaved well in the atmospheric tests.

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In 1940 the Protective Coatings (Corrosion) Sub-Committee began extensive exposure tests of metallic coatings for the protection of heavy structural steelwork; some representative non-metallic coatings other than oil paint were also included in the investigation. Most of the specimens were freely exposed to the atmosphere, but a few were immersed in the sea. The results of observations during the first five years' exposure have already been described in two papers, relating to the metallic coatings[1] and the non-metallic coatings,[2] respectively.

Further results of these experiments are given in the present report. They are based on observations made up to the end of the sea-immersion tests after six years and covering up to 12 years for the atmospheric tests, which are still in progress on the more resistant coatings.

EXPERIMENTAL DETAILS

Specimens and Protective Schemes

The experimental programme was drawn up with special reference to the protection of heavy structural steelwork. Full details were given in the 5-year reports,[1, 2] but it may be helpful to repeat the essential features here.

Seven different metal coatings were tested: aluminium, cadmium, cadmium–zinc (82/18) alloy, lead, lead–tin (88/12) alloy, tin, and zinc. These were applied to specimens of mild steel (0·2% of carbon), measuring 15 in. × 10 in. × $\frac{3}{8}$ in., by a variety of processes including, where appropriate, cementation, electrodeposition, hot-dipping, and spraying. So far as possible, all the specimens were prepared under practical industrial conditions with the generous collaboration of several firms and institutions. A standard coating thickness of 3 mils (0·003 in.) was aimed at throughout, but some of the coatings were also applied at nominal thicknesses of 1 or 5 mils. A few of the specimens tested in the atmosphere were painted with two coats of red oxide in linseed-oil paint, but otherwise the metal coatings were tested bare.

Several non-metallic coatings, such as cement–asbestos, vitreous enamel,* paints in a lanolin medium, or sprayed bitumen, were included in the tests.

Atmospheric Exposure Tests

Atmospheric corrosion tests are in progress at three sites in Great Britain:

- Sheffield (an industrial atmosphere)
- Llanwrtyd Wells (a rural atmosphere with a heavy saline rainfall)
- Calshot (a marine atmosphere)

and at two sites overseas:

- Congella, near Durban, South Africa (a marine atmosphere)
- Apapa, near Lagos, Nigeria (a tropical marine atmosphere).

Paper MG/BA/47/52 of the Protective Coatings (Corrosion) Sub-Committee of the Corrosion Committee of the British Iron and Steel Research Association, first received 1st April, 1953, and in its final form on 17th August, 1953.

Mr. Stanners is a member of the Association's Corrosion Laboratory, of which Dr. Hudson is Head.

* Ingot iron was used instead of the 0·2%C steel for vitreous enamelling.

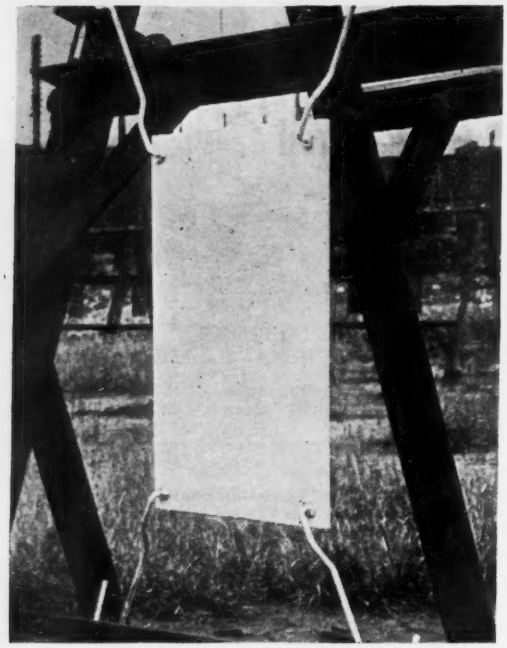

Fig. 1—Method of exposure

Meteorological data and other particulars of these sites are given in Table I. Some specimens were also exposed at Singapore, but these were lost during the Japanese invasion.

A complete set of coatings was tested at Sheffield, but elsewhere tests were made on selected coatings only. Duplicate specimens were exposed throughout. The specimens were hung vertically on steel stands, facing south, in two horizontal rows at about 5 ft. and 3 ft. from the ground (*see* Fig. 1). Each member of a pair was exposed in a different row and on a different stand, so as to minimize any positional effect.

The present position of the atmospheric tests (February, 1953) may be judged from the fact that about 215 specimens out of an original number of about 400 are still exposed. Nearly 170 of these specimens, including 53 at Sheffield, have not yet failed.

Sea-Immersion Tests

Two sets of specimens were immersed in the sea. The first set was tested at Caernarvon to ascertain the effect of metallic coatings on the performance of ships' bottom compositions.[3] The experiment ended in 1942 and led to the general conclusion that metallic coatings were beneficial under paint.

The second set of specimens was immersed at Gosport. As previously described,[1, 2] all the badly corroded specimens of this set were removed after 2 years' immersion, and the remainder, consisting entirely of zinc-coated specimens, were transferred to the seawater exposure pool of the Admiralty Metallurgical Laboratory at Emsworth, where they were immersed for a further 4 years.

Methods of Inspection

Atmospheric Exposure—Inspections of the specimens on atmospheric test are made at suitable intervals. Records are taken of any blistering or flaking of the coating and estimates are made of the percentage of the surface that is (*a*) discoloured, (*b*) rust-stained, or (*c*) rusted.* Separate observations are made for the front and back surfaces, and each surface is also given one of the following gradings:

- *x* *Excellent:* No sign of breakdown of the coating
- *f* *Fair:* Signs of breakdown of the coating itself over less than 5% of the surface, whether accompanied by rusting or not
- *o* *Failed:* Rusted over 5% or more of the surface.†

These gradings are used to deduce the effective life of the protective scheme. In the previous reports two

* The edges are disregarded when making these estimates but, if desirable, their condition is recorded. Moreover, obvious mechanical damage to the coating is ignored, although for practical purposes the ability of a coating to resist damage must be taken into consideration.

† The criterion of 5% of rusting would now be considered too high a permissible limit, at least for certain protective coatings. For example, in the opinion of B.I.S.R.A. Joint Technical Panel J/P1 (Paints for Structural Steelwork) a steel structure should be repainted when 0·2–0·5% of its surface has rusted.

Table I
ATMOSPHERIC EXPOSURE SITES

Site	Approximate Position		Average Meteorological Data			Corrosion Rate,* mils/year		Date of Exposure
	Latitude	Longitude	Temperature, °F.	Rainfall, in./year	Relative Humidity, %	Ingot Iron	Zinc	
Home								
Sheffield	53° N.	1° W.	48	30	84	5·5	0·58	16.7.40
Llanwrtyd Wells	52° N.	4° W.	47	55	79	2·6	0·11	6.8.40
Calshot	51° N.	1° W.	51	26	84	3·4	0·14	27.8.40
Overseas								
Congella, S. Africa	30° S.	31° E.	71	43	76	5·2	0·24	8.4.42
Apapa, Nigeria	7° N.	4° E.	80	72	79	1·2	0·05	20.3.41

* The figures are for reference specimens 4 in. × 2 in. × $\frac{1}{8}$ in. (ingot iron) or × $\frac{1}{32}$ in. (zinc) exposed bare and changed annually. Average values are given for the years during which the coated specimens have been exposed

different figures were given: estimates of the time taken to reach grade 'fair' and of that taken to reach grade 'failed.' Further experience has shown that it is difficult to interpret grade 'fair.' For example, strictly this grade is reached for a painted metallic coating when the paint alone shows sign of breakdown. In the present report, therefore, estimates are given only for the life to grade 'failed.'

Specimens graded as 'failed' on both surfaces at two or more successive inspections are removed from the exposure sites. On their return to the laboratory they are washed and weighed before a final examination of the coating is made. The changes in weight of the specimens on exposure have not proved to be of great significance, and, in the main, visual estimates of rusting have been found to be the most reliable index of coating breakdown.* Even the latter are sometimes difficult to interpret. This is particularly true for certain coatings (*e.g.*, some sprayed aluminium coatings) that become heavily rust-stained in the early stages of exposure but then seem to suffer little further serious breakdown over a long period. Difficulty also arises with coatings of the enveloping type, such as cement–asbestos, where failure only becomes apparent when the coatings crack or flake off. In a few cases, noted later in the Tables of results, these difficulties have led to the premature removal of specimens from test.

Sea Immersion—Regular inspections of the specimens immersed in the sea were impracticable. The results of these tests are therefore based on the final inspections made after removal and cleaning.

RESULTS

The results of the tests to date are given in Tables II–V, in which the symbols used have the following meanings:

W: Weight of coating, oz./sq. ft.† For painted specimens, *a* is the weight of the metal coating and *b* is the total weight of the dry paint film.

L: Life, in years, to grade 'failed' (5% of rust), mean value for the front and back surfaces. A 'greater than' sign (>) denotes that one or both surfaces had not failed at the last recorded inspection or, in a few cases, when the specimen was prematurely removed from test.

In the atmospheric exposure tests the agreement between duplicate specimens was generally good, so that it has been thought sufficient to give the average values for both specimens in Tables II, III, IV, and VI; the few exceptions, in which marked discrepancies occurred between duplicates, have been listed individually in Table II*a*. Individual results are given, however, in Table V for specimens immersed in the sea. For these, the life to failure *L* of the coating could not be estimated. Visual estimates of the discoloration, rust-staining, and rust on each surface were made when the specimens were returned to the laboratory, and their losses in weight were determined after they had been cleaned under running water with a bristle brush.

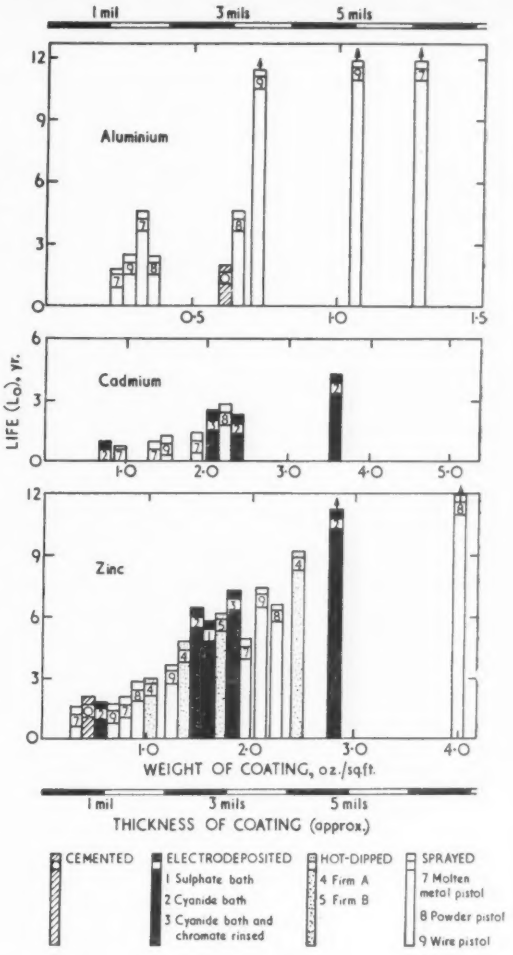

Fig. 2—Performance of metal coatings at Sheffield

DISCUSSION OF RESULTS

Effect of Coating Thickness

The results have confirmed the commonsense assumption that the value of a given type of coating is closely related to its thickness. This is generally true for coatings of aluminium, cadmium, and zinc (*see* Fig. 2). The effect of differences in coating thickness should therefore be borne in mind when comparing coatings of different types. For example, a cemented (sherardized) zinc coating, which is limited by the nature of the process to a maximum weight of about 1 oz./sq. ft., cannot be expected to have such a good corrosion resistance as the much heavier zinc

* Attempts to measure the residual thickness of the corroded metallic coatings by means of a thickness tester have met with little success, because the presence of rust interferes with the accuracy of the determinations.

† This is regarded as a more practical unit than the weight of coating in grammes per specimen used in the previous report. The total area of a specimen is 2·23 sq. ft. Hence, 1 oz./sq. ft. corresponds approximately to 60 g./specimen.

Table II

RESULTS OF ATMOSPHERIC EXPOSURE TESTS ON METALLIC COATINGS

Coating and Process	Exposure Sites[a]									
	Sheffield (11·9 years)		Llanwrtyd Wells (11·5 years)		Calshot (12·0 years)		Congella (9·1 years)		Apapa (11·0 years)	
	W, oz./sq. ft.	*L*, years	*W*, oz./sq. ft.	*L*, years	*W*, oz./sq. ft.	*L*, years	*W*, oz./sq. ft.	*L*, years	*W*, oz./sq. ft.	*L*, years
1. Aluminium										
Cemented (calorized)	0·62	2·0	0·54	0·1	0·69	0·1				
Hot-dipped	2·22	>11·3	2·05	(1·0)	2·18	(>6·7)[f]	2·01	(>5·6)[b,f]	1·92	(9·5)[b]
Hot-dipped and heat-treated	2·09	(2·9)	2·33	(0·3)	2·32	>6·0[f]				
Sprayed by molten-metal pistol	0·24	1·7[f]								
	0·33	4·6[f]	0·47	>9·3[f]	0·33	>6·5[f]	0·40	>7·4		
	1·25	>11·9								
Sprayed by powder pistol	0·33	2·4								
	0·63	4·6[f]	0·78	0·6	0·49	>6·9[f]	0·60	(>4·0)[b,f]		
	1·61	2·2								
Sprayed by wire pistol	0·31	>2·2[b]								
	0·71	>11·4[c]	0·78	>*11·5*	0·68	>*12·0*	0·69	>9·1	0·74	>11·0
	1·04	>11·9								
2. Cadmium										
Electrodeposited, cyanide bath	0·72	1·0	0·71	>10·8						
	2·17	2·3	2·03	>*11·5*	2·15	>*12·0*				
	3·46	4·2								
Electrodeposited, cyanide bath, and chromate rinsed	2·14	2·5								
Sprayed by molten-metal pistol	0·91	0·7								
	1·30	1·0	1·09	>11·0	1·22	8·5	1·17	6·4		
	1·84	1·4								
Sprayed by powder pistol	2·16	2·8	1·51	>11·5						
Sprayed by wire pistol	1·45	1·3								
3. Cadmium–Zinc (82/18) Alloy										
Sprayed by molten-metal pistol	0·44	0·8								
	1·08	1·1	0·62	9·1	0·98	6·8	0·88	5·2		
	1·72	(1·4)								
Sprayed by powder pistol	0·95	1·4	1·02	>11·1						
4. Zinc										
Cemented (sherardized)	0·54	2·0[e]	0·54	>9·4[e]	0·49	8·8				
Electrodeposited, sulphate bath	1·75	5·7	1·72	>*11·5*	1·69	>*12·0*				
Electrodeposited, cyanide bath	0·55	1·8	0·60	>*11·5*	0·58	>10·7				
	1·72	6·4	1·79	>*11·5*	1·76	>*12·0*	1·80	>9·1	1·76	>11·0
	2·86	>11·2								
Electrodeposited, cyanide bath, and chromate rinsed	1·79	7·2								
Hot-dipped (firm A)	1·00	3·0	1·01	>*11·5*	1·07	>*12·0*				
	1·45	4·7	1·49	>*11·5*	1·49	>*12·0*	1·37	>9·1	1·44	>11·0
	2·50	9·2								
Hot-dipped (firm B)	1·73	6·1	1·88	>*11·5*	1·94	>*12·0*				
Sprayed by molten-metal pistol	0·43	1·6[d]								
	0·82	2·0	1·02	>*11·5*	0·94	10·3	1·14	>9·1		
	1·79	4·9								
Sprayed by powder pistol	0·93	2·8								
	2·30	6·6	2·97	>*11·5*	2·31	>*12·0*	3·04	>9·1		
	4·07	>11·9								
Sprayed by wire pistol	0·53	1·7	0·46	>*9·1*						
	1·27	3·6[e]	1·60	>11·5	1·58	>*12·0*[e]	1·72	>9·1	1·50	>11·0
	2·13	7·4								
5. Lead										
Electrodeposited, perchlorate bath	0·98	6·9	0·95	(1·3)						
	2·93	>*11·9*	2·88	>11·1	3·07	>*12·0*				
	4·82	>11·9								
Hot-dipped	0·69	7·3	0·61	(0·6)	0·69	(1·0)				
Sprayed by molten-metal pistol	1·84	6·6[f]								
	2·77	>7·6[f]	2·90	>9·6	3·02	(>6·7)[f]	3·32	(>5·6)[b,f]		
	4·04	>11·9								
Sprayed by powder pistol	1·10	5·1			0·98	(1·2)				
			2·52	>11·1						
Sprayed by wire pistol	3·97	>*11·9*	3·81	>9·3	4·31	>*12·0*			3·78	>11·0
6. Lead–Tin (88/12) Alloy										
Hot-dipped	0·43	(>7·0)	0·43	(1·0)					0·37	4·5
Sprayed by molten-metal pistol	1·42	5·0								
	2·13	>11·2			2·13	(1·2)				
	2·40	>11·0	2·47	(1·3)			2·40	(>4·8)[b,f]		
Sprayed by powder pistol	4·00	>11·9			3·46	(1·0)				
7. Tin										
Electrodeposited, stannate bath	1·80	>*11·9*	1·85	2·4	1·51	1·0				
Hot-dipped	0·35	5·9								
Sprayed by molten-metal pistol	0·56	(1·5)[f]								
	0·74	(5·9)[f]	0·82	(0·6)	0·89	0·7[f]	0·97	0·9[f]		
	1·61	>11·9								
Sprayed by powder pistol	2·29	3·0			2·44	(0·8)				

coatings that can be applied by electrodeposition, hot-dipping, or spraying.

Bare Metallic Coatings Exposed to the Atmosphere

A general survey of the results of the atmospheric tests on bare metallic coatings is most readily obtained by studying the results for the coatings that were exposed at all three home stations, because few of the limited number of coatings exposed at Apapa or Congella have yet failed. Due attention should be paid to differences in the weight of the same type of coating on specimens at different stations, but with the exception of the lead coatings sprayed by the powder pistol, which were twice as heavy on the Llanwrtyd Wells specimens as on those at Sheffield or Calshot, these differences were generally small.

The Most Efficient Coatings—The simplest procedure for choosing the most efficient protective coatings in these experiments is to take an average life for the three home stations, although at this stage of the research the method is necessarily weighted in favour of the results at Sheffield, as few coatings have yet failed at Llanwrtyd Wells or Calshot. By this criterion, three coatings stand out as having average lives that already exceed 11 years (*see* Figs. 3–6):

	Average Coating Weight, oz./sq. ft.
Aluminium, sprayed by the wire pistol	0·7
Lead, electrodeposited	3·0
Lead, sprayed by the wire pistol	4·0

They are followed by four zinc coatings, with an average life of about 10 years:

	Average Coating Weight, oz./sq. ft.
Zinc, electrodeposited from a sulphate bath (*see* Fig. 7)	1·7
Zinc, electrodeposited from a cyanide bath	1·9
Zinc, hot-dipped (firm *B*)	1·9
Zinc, sprayed by the powder pistol	2·5

The main conclusion to be drawn from the tests so far is, therefore, that protection against atmospheric corrosion for at least 10 years can be obtained in Great Britain from suitably applied aluminium coatings weighing about $\frac{3}{4}$ oz./sq. ft. or from lead coatings weighing about 3 oz./sq. ft.* Zinc coatings of about 2 oz./sq. ft. will give this degree of protection in all but severely corrosive industrial atmospheres, where 3 oz./sq. ft. are needed to ensure a 10 years' life.

Lead coatings show to particular advantage in the sulphur-laden atmosphere of Sheffield, no doubt because a protective film of sulphate forms on them. They are, however, difficult to apply, except by electrodeposition, at the substantial thicknesses that have given good results in this research. Zinc coatings, although valuable, are rather less resistant to an industrial atmosphere than either lead or aluminium coatings. Consequently, aluminium is to be regarded

* This statement is strictly true for large flat vertical surfaces only, because the complicating effects of design may reduce the duration of protection obtained at parts of an actual structure, *e.g.*, at crevices or at the edges of plates or sections. No simple exposure test can allow for these practical factors.

Table II*a*

CASES OF MARKED DIVERGENCE BETWEEN DUPLICATES

Coating and Process	Exposure Sites[a]									
	Sheffield (11·9 years)		Llanwrtyd Wells (11·5 years)		Calshot (12·0 years)		Congella (9·1 years)		Apapa (11·0 years)	
	W, oz./sq. ft.	*L*, years	*W*, oz./sq. ft.	*L*, years	*W*, oz./sq. ft.	*L*, years	*W*, oz./sq. ft.	*L*, years	*W*, oz./sq.ft.	*L*, years
1. Aluminium										
Hot-dipped					2·15	(1·5)	1·83	>9·1		
					2·20	>12·0	2·18	(>2·1)[b]		
Hot-dipped and heat-treated					2·31	0·1				
					2·32	>12·0				
Sprayed by molten-metal pistol	0·22	0·7								
	0·25	2·8								
	0·28	2·0	0·44	>11·5	0·28	1·5				
	0·38	7·2	0·49	>7·1[g]	0·38	>11·5				
Sprayed by powder pistol	0·62	7·2			0·46	>11·7	0·58	(>6·0)[b]		
	0·63	2·0			0·51	2·1	0·62	(>2·1)[b]		
5. Lead										
Sprayed by molten-metal pistol	1·55	9·5								
	2·13	3·8								
	2·21	5·8			2·56	(1·5)	3·03	(>2·1)[b]		
	3·32	>9·4			3·48	>12·0	3·60	>9·1		
6. Lead–Tin (88/12) Alloy										
Sprayed by molten-metal pistol							1·85	>7·5[b]		
							2·95	(>2·1)[b]		
7. Tin										
Sprayed by molten-metal pistol	0·52	(1·6)								
	0·60	1·5								
	0·68	(1·6)			0·62	0·4	0·90	1·6		
	0·79	10·3			1·15	1·0	1·03	0·3		

Notes to Tables II and IIa

a The time given under the name of each site is the duration of exposure to the latest inspection. Each value represents the mean result for 2 specimens. Lives in parentheses are approximate (*see* section on 'Methods of Inspection')
b Removed before the 'failure' point
c Average for 3 specimens
d One specimen only
e Average for 4 specimens
f *See* Table II*a*
g Front face failed very early, back face still not failed

Table III

RESULTS OF ATMOSPHERIC EXPOSURE TESTS ON PAINTED METALLIC COATINGS

Coating and Process	Exposure Sites*								
	Sheffield (11·9 years)			Llanwrtyd Wells (11·5 years)			Calshot (12·0 years)		
	W, oz./sq. ft.†		*L*, years	*W*, oz./sq. ft.†		*L*, years	*W*, oz./sq. ft.†		*L*, years
	a	*b*		*a*	*b*		*a*	*b*	
Two coats of red oxide in linseed oil over the following metallic coatings:									
Aluminium, cemented	0·71	0·78	>11·9	0·59	0·74	>11·5			
Aluminium, sprayed by wire pistol	0·28	0·42	>11·9						
	0·78	0·41	>11·9	0·70	0·43	>11·5			
Zinc, cemented	0·58	0·34	7·9	0·56	0·33	>11·5	0·60	0·33	>10·4
Zinc, hot-dipped	1·01	0·32	8·5						
	1·45	0·31	10·9	1·53	0·31	>11·5			
Zinc, sprayed by wire pistol	0·49	0·38	6·9						
	1·51	0·41	>11·9	1·55	0·42	>11·5			
Lead, electrodeposited	0·98	0·32	>11·9						
	2·92	0·34	>11·9	2·90	0·33	>11·5			
Bare steel (coating 1*a* of Table IV)	—	0·34	6·8	—	0·36	>11·5	—	0·34	>10·4

* The time given under the name of each site is the duration of exposure to the latest inspection. Each value represents the mean result for two specimens

† *a* = metallic coating, *b* = paint

as the most generally serviceable coating metal of the three.

Other (Less Durable) Coatings—Little need be said about the less durable coatings, but the following comments may be of interest:

(i) Tin and lead–tin alloy coatings, at the thicknesses used for these tests, do not protect steel well. For the reason mentioned above when discussing lead coatings, the behaviour of the lead–tin alloy coating at Sheffield is an exception to this statement. Some of the heavy tin coatings have also done well at Sheffield.

(ii) At Llanwrtyd Wells and Calshot no difference has been observed between cadmium coatings and zinc coatings. At Sheffield, however, cadmium was much inferior to zinc, the lives of electrodeposited coatings 3 mils thick being 2·3 years for cadmium but 5·7 or 6·4 years for zinc. The failure of a sprayed cadmium coating at Congella is shown in Fig. 8.*

(iii) It is difficult to assess the value of the cemented (calorized) and hot-dipped aluminium coatings, because these coatings became rust-stained at an early stage of exposure. This rust-staining is due to the corrosion of the coatings themselves, which contain iron, and it may be mistaken for rusting of the steel base. There is no doubt that the calorized specimens failed within a few years, but the hot-dipped aluminium coatings are still exposed and, despite their rusty appearance, there has been no marked wastage of the steel beneath them. The chief industrial application of these coatings is for the protection of steel at elevated temperatures, and outstanding powers of ' weather resistance ' have not been claimed for them.

(iv) The results obtained for sprayed aluminium coatings applied by the powder pistol are open to doubt, because the aluminium used contained 3% of copper (*see* Hudson and Banfield,[1] p. 241P). These tests are therefore being repeated, and a suitable range of specimens has been included in a second series of tests on protective metallic coatings for steel, begun by the Sub-Committee in 1950.

(v) The protection afforded by zinc coatings has proved to be roughly proportional to their weight and independent of the coating process. Thus, weight for weight, sherardized coatings, electrodeposited coatings, hot-dipped coatings, and sprayed coatings applied by all three spraying pistols have given equal service. This conclusion is in agreement with recent results obtained by Gilbert for hot-galvanized coatings[4] and does not necessarily conflict with the findings of Hadden,[5] who observed that the protection given by hot-galvanized coatings was improved by annealing them so as to increase their iron content. In Hadden's experiments the improvement did not become appreciable until the iron content of the coating rose above 10%. The iron content of the sherardized coatings included in the present investigation may have exceeded this figure, but it is improbable that that of the hot-dipped coatings did so; the electrodeposited and sprayed coatings were, of course, practically free from iron.

(vi) Treatment of electrodeposited cadmium or zinc coatings with a simple chromic-acid wash* has had a slightly beneficial effect on their protective values. The average lives of untreated coatings were 2·3 years for cadmium and 6·4 years for zinc, compared with 2·5 years and 7·2 years, respectively, for rinsed coatings (*see* Table II). The significance of these differences is not great, because the results relate to single pairs of specimens only.

Metallic Coatings + Red-Oxide Paint

The performance of the composite protective schemes consisting of a metallic coating plus two coats of red oxide in linseed-oil paint is illustrated by Figs. 9–13. The paint itself probably ceased to protect most of the specimens several years ago. Full information on how far it has prolonged the life of the metal coatings will not be available for some years; interim results are given in Table VI.

At Sheffield the paint has lasted much longer on the lead and aluminium coatings than on the zinc coatings. The average increase in the duration of protection due to painting over the zinc coatings, now about 6·2 years, may prove to be less than the

* The photograph illustrates the tendency of sprayed metal coatings to fail at the boundaries of the spray lines. This tendency has been reduced by improvements in spraying technique made since the tests under discussion were begun more than 13 years ago.

* The wash consisted of a solution of 1% chromic acid + 0·1% sulphuric acid, and was used at 18° C.

Base of specimen

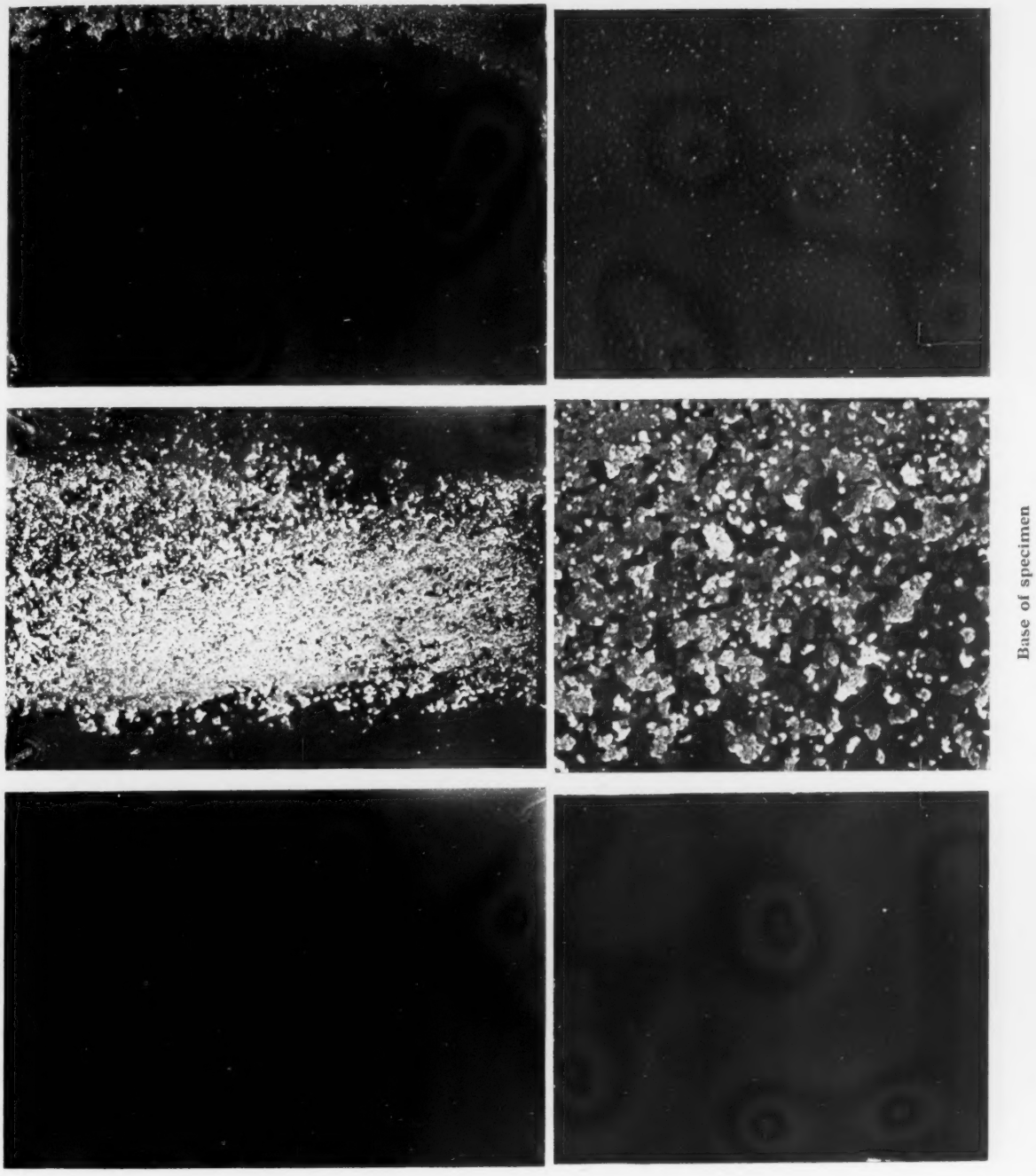

Fig. 3 (top)—Aluminium coating after 10 years' exposure at Sheffield. Sprayed by wire pistol; coating weight 0·74 oz./sq. ft.

Fig. 4 (centre)—Lead coating after 10 years' exposure at Sheffield. Electrodeposited (perchlorate bath); coating weight 2·92 oz./sq. ft.

Fig. 5 (bottom)—Lead coating after 10 years' exposure at Sheffield. Sprayed by wire pistol; coating weight 3·84 oz./sq. ft.

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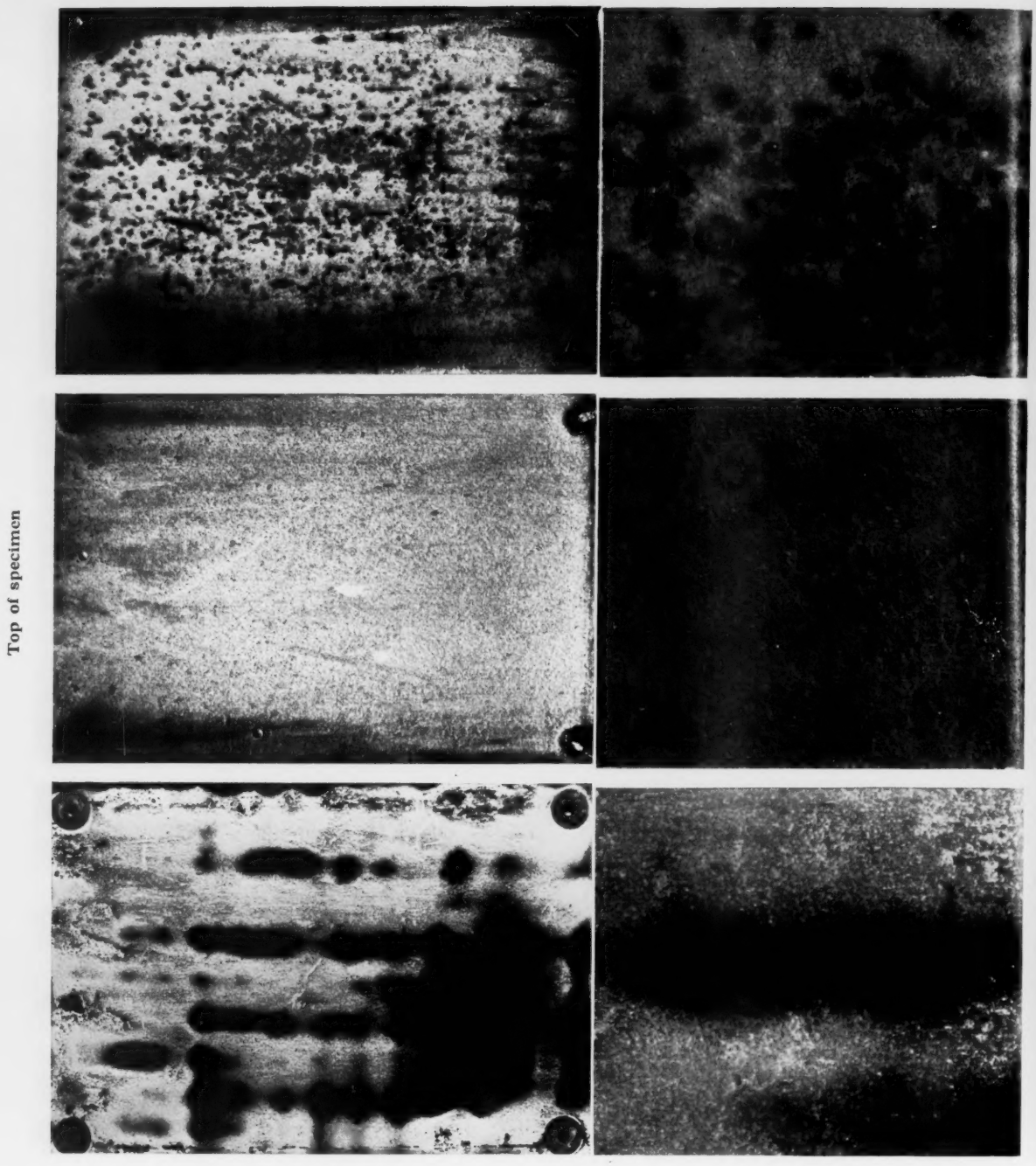
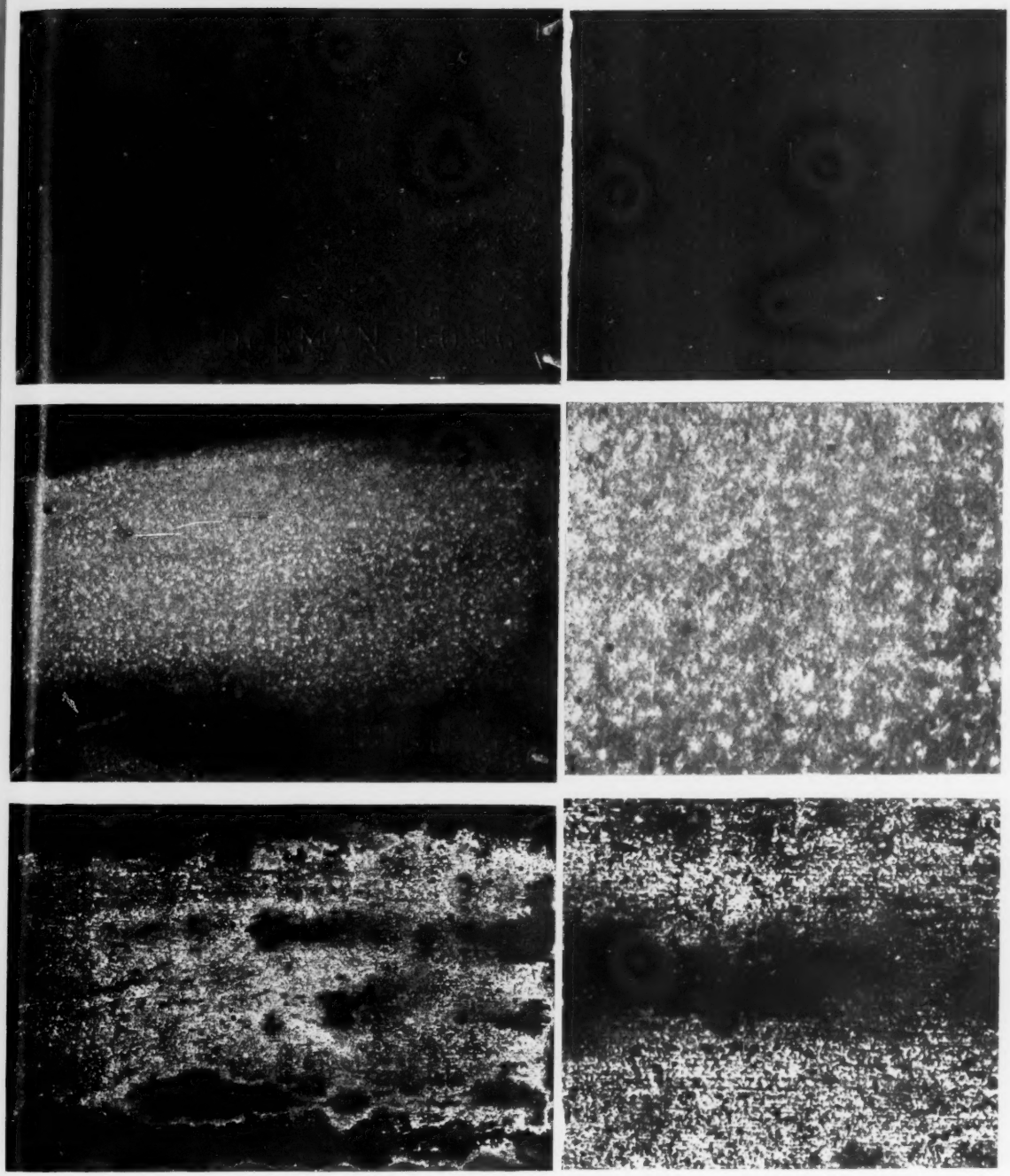


Fig. 6 (top)—Lead coating after 10 years' exposure at Calshot. Electrodeposited (perchlorate bath); coating weight 3·19 oz./sq. ft.

Fig. 7 (centre)—Zinc coating after 10 years' exposure at Calshot. Electrodeposited (sulphate bath); coating weight 1·74 oz./sq. ft.

Fig. 8 (bottom)—Cadmium coating after 7½ years' exposure at Congella. Sprayed by molten-metal pistol; coating weight 1·26 oz./sq. ft.



Specimens, × ¼ linear

Part of surface, actual size

Figs. 9–11—Red oxide in linseed-oil paint (2 coats) over metallic coatings, after 12¼ years' exposure at Sheffield
Fig. 9 (top)—Aluminium, cemented; metal coating weight 0·68 oz./sq. ft., dry paint weight, 0·78 oz./sq. ft.
Fig. 10 (centre)—Aluminium, sprayed by wire pistol; metal coating 0·73 oz./sq. ft., dry paint 0·41 oz./sq. ft.
Fig. 11 (bottom)—Zinc, sprayed by wire pistol; metal coating 1·50 oz./sq. ft., dry paint 0·41 oz./sq. ft.

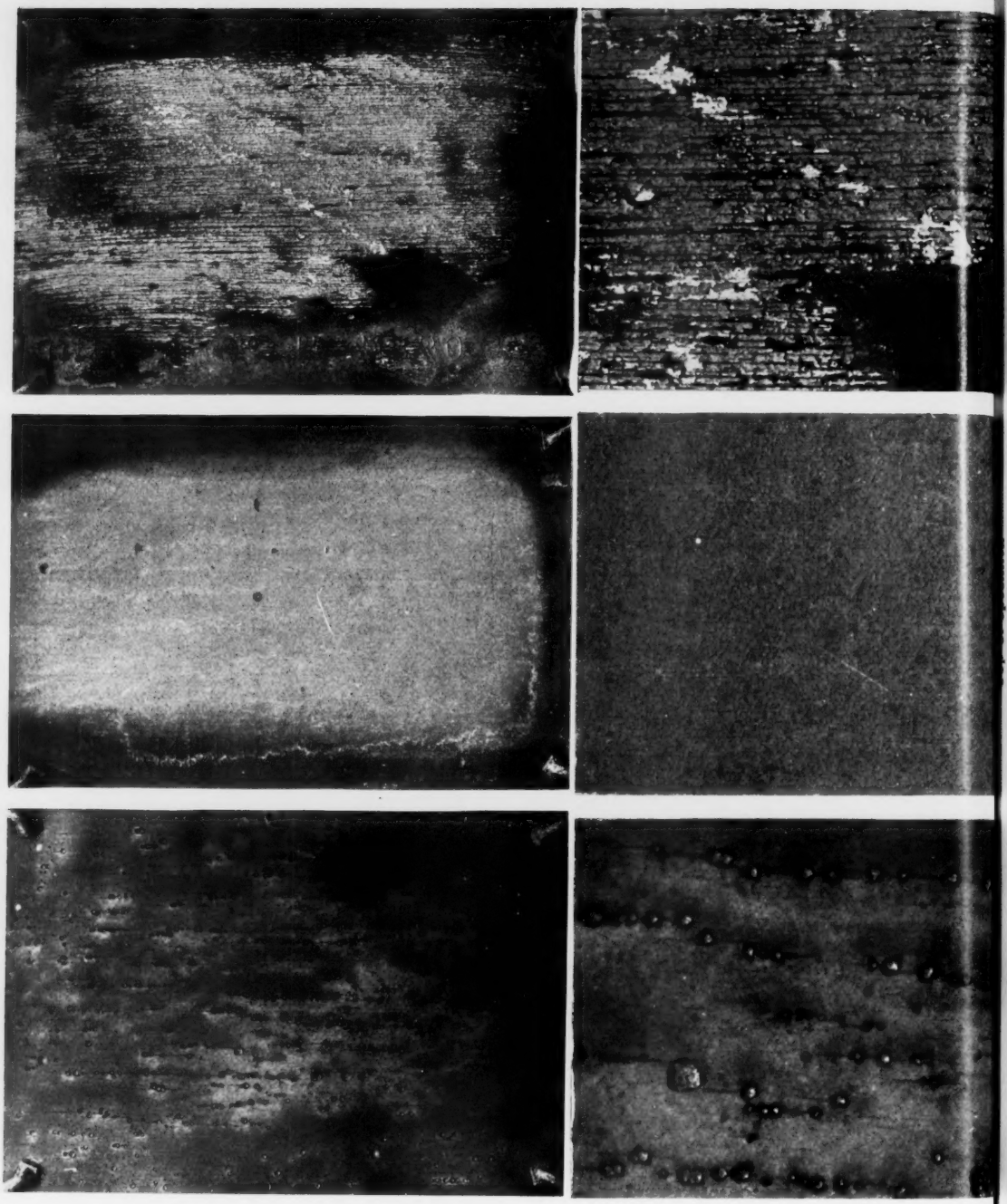


Fig. 12 (top)—Red oxide in linseed-oil paint (2 coats) over zinc, hot-dipped, after 12¼ years' exposure at Sheffield. Metal coating 1·42 oz./sq. ft., dry paint 0·32 oz./sq. ft.

Fig. 13 (centre)—Red oxide in linseed-oil paint (2 coats) over lead, electrodeposited, after 12¼ years' exposure at Sheffield. Metal coating 2·94 oz./sq. ft., dry paint 0·35 oz./sq. ft.

Fig. 14 (bottom)—Pickled mild steel painted with red lead in linseed-oil paint (2 coats) and red oxide in linseed-oil paint (3 coats), after 12¼ years' exposure at Sheffield. Dry paint weight 0·95 oz./sq. ft.

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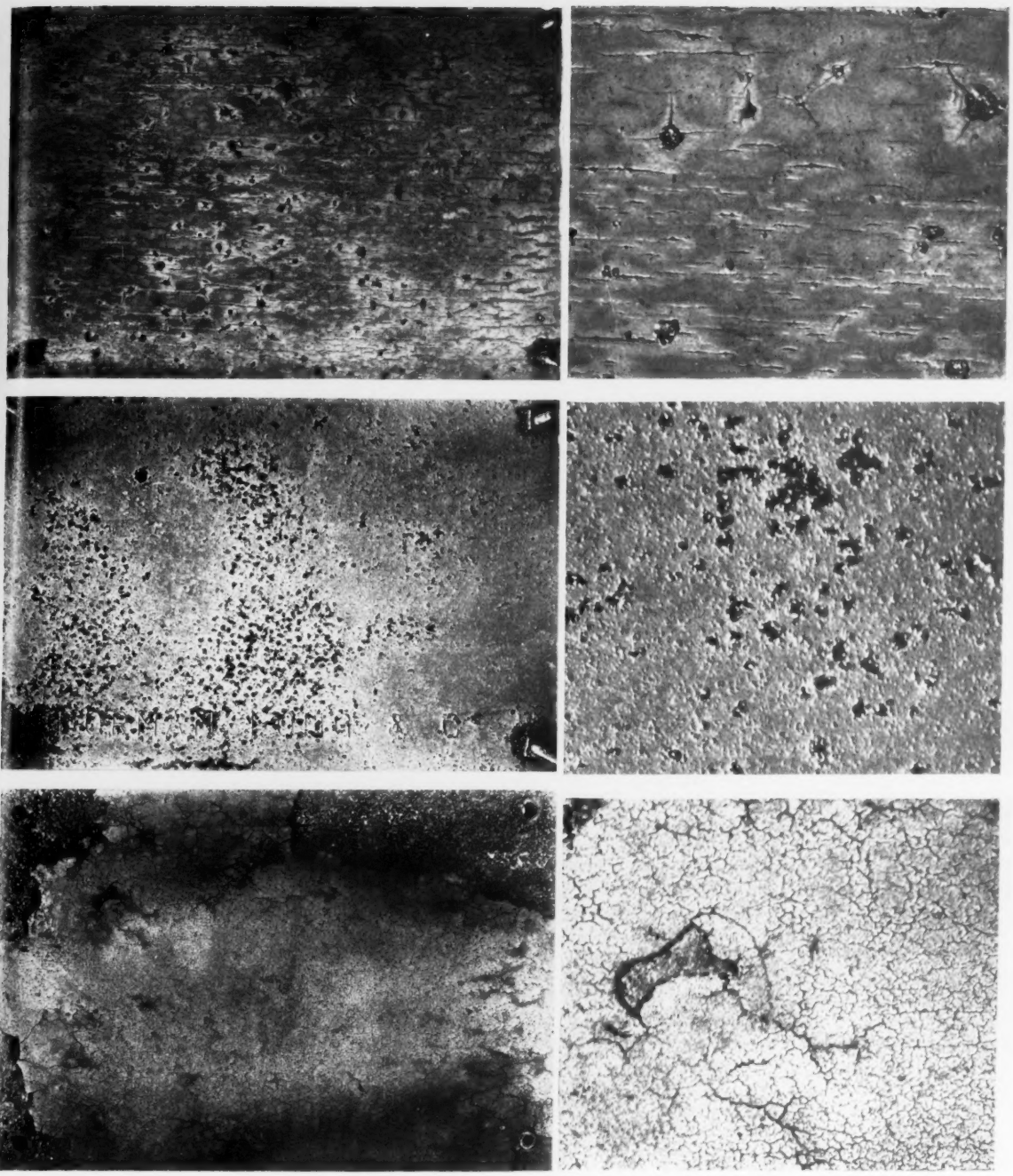


Specimens, × ¼ linear

Part of surface, actual size

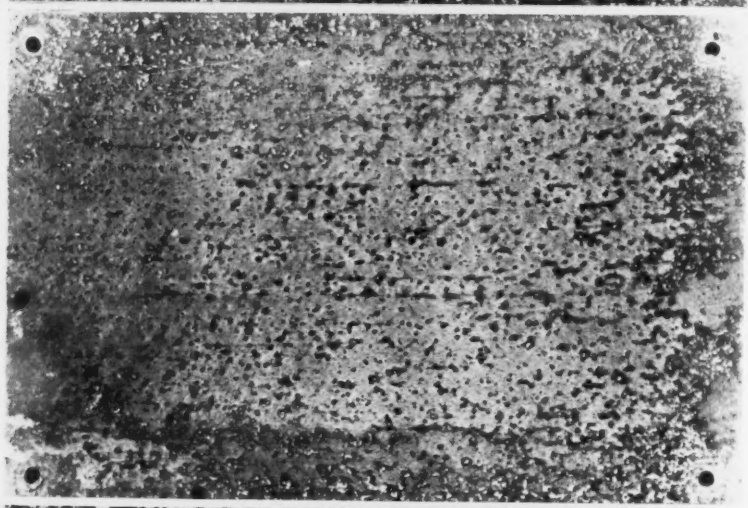
Fig. 15 (top)—Pickled mild steel painted with red lead in linseed-oil paint (2 coats) and red oxide in linseed-oil paint (3 coats), after 10 years' exposure at Calshot. Dry paint weight 0·90 oz./sq. ft.

Fig. 16 (centre)—Hot-sprayed paint coating applied to pickled mild steel, after 10 years' exposure at Calshot. Coating weight 0·38 oz./sq. ft.

Fig. 17 (bottom)—Rubber-wax sheathing applied to as-rolled mild steel, after 10 years' exposure at Calshot. Coating weight 5·44 oz./sq. ft.

[*Hudson and Stanners*

Fig. 18—Lanolin-base priming paint *A* (2 coats) + red oxide in linseed-oil paint (2 coats). Dry paint weight 0·60 oz./sq. ft.



Top of specimen

Fig. 19—Red lead in linseed-oil priming paint (2 coats) + red oxide in linseed-oil paint (2 coats). Dry paint weight 0·93 oz./sq. ft.

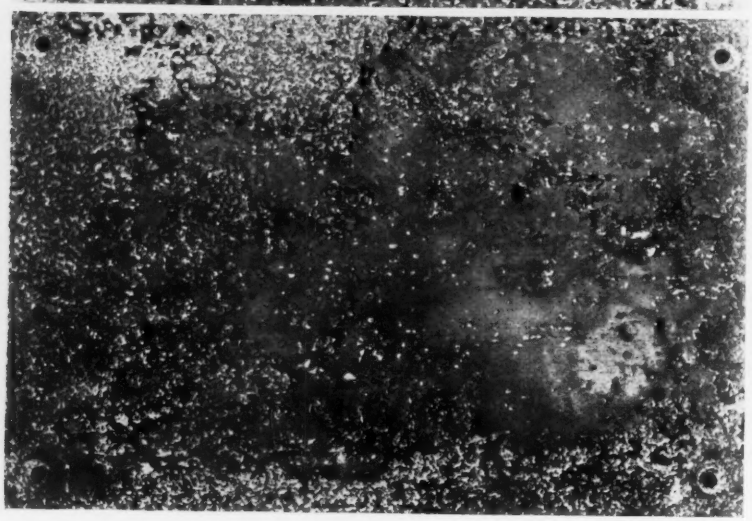


Fig. 20—Lanolin-base priming paint *B* (2 coats) + red oxide in linseed-oil paint (2 coats). Dry paint weight 0·69 oz./sq. ft.

Figs. 18–20—Painting schemes applied to pickled copper-bearing mild steel, after 10 years' exposure at Llanwrtyd Wells

life of the painting schemes on pickled steel alone (6·8 years). It is improbable that the lives of a metal coating and of a painting scheme applied over it will be entirely additive, because once the paint film begins to break down it acts as a sponge and accelerates the corrosion of the metal coating by maintaining moisture in contact with the surface.

Little has emerged so far from the tests at Llanwrtyd Wells, except that painting has improved the performance of the cemented aluminium coating considerably. The improvement, which is also marked at Sheffield, may, however, be more apparent than real, because the gradings of the unpainted specimens are adversely affected by the rusting of the coating itself.

Further light should be thrown on the behaviour of composite protective schemes of metal coatings and paint by some tests begun in 1948 by B.I.S.R.A.[6]

Sundry Non-Metallic Coatings

The results given in Table IV for sundry non-metallic coatings exposed to the atmosphere are best discussed individually for each type of coating.*

Painting Schemes—The results bring out once again the value of protective schemes based on red lead in linseed-oil priming coats. Schemes 1*b* and 1*c*, which include a red lead in linseed-oil priming paint, have protected the specimens adequately at Sheffield for nearly 12 years (*see* Figs. 14 and 15).† The proprietary painting schemes (and red oxide in linseed-oil paint when used alone) have been less satisfactory, but

* Descriptions of the coatings concerned will be found in the earlier report.[2]

† Photographs of the surfaces shown in Figs. 15, 16, 18, 19, and 20 after shorter durations of exposure have already been published.[2]

Table IV

RESULTS OF ATMOSPHERIC EXPOSURE TESTS ON NON-METALLIC COATINGS

Coating Process	Exposure Sites*									
	Sheffield (11·9 years)		Llanwrtyd Wells (11·5 years)		Calshot (12·0 years)		Congella (9·1 years)		Apapa (11·0 years)	
	W, oz./sq. ft.	*L*, years	*W*, oz./sq. ft.	*L*, years	*W*, oz./sq. ft.	*L*, years	*W*, oz./sq. ft.	*L*, years	*W*, oz./sq. ft.	*L*, years
A. PAINTING SCHEMES										
1. *Over Steel Pickled by the Sulphuric-Acid/Phosphoric-Acid Process*										
a. Red oxide in linseed-oil paint (2 coats)	0·34	6·8	0·36	>11·5	0·34	>10·4				
b. Red lead in linseed-oil paint (1 coat), red oxide in linseed-oil paint (3 coats)	0·69	>11·9	0·74	>10·1	0·71	>12·0				
c. Red lead in linseed-oil paint (2 coats), red oxide in linseed-oil paint (3 coats)	0·94	>11·5	0·94	>11·5	0·94	>12·0			0·92	8·4‡
d. Proprietary paints bound with alkyd-resin media (2 coats)	0·18	> 8·0†	0·18	> 7·9						
e. Inhibitive wash, followed by a 2-coat proprietary painting scheme	0·19	7·7								
2. *Over Weathered and Wire-Brushed Steel*										
a. As process 1*e* above	0·22	1·0	0·23	0·9	0·22	1·7				
3. *Over Steel Pickled with Sulphuric Acid*										
a. Lanolin priming paint *A* (2 coats), red oxide in linseed-oil paint (2 coats)	0·62	>11·9	0·60	4·2			0·62	5·0		
b. Lanolin priming paint *B* (2 coats), red oxide in linseed-oil paint (2 coats)	0·70	>11·9	0·69	4·6			0·66	5·9		
c. Red lead in linseed-oil paint (2 coats), red oxide in linseed-oil paint (2 coats)	0·90	>11·9	0·93	7·3			0·93	>6·6†		
B. SPRAYED COATINGS										
4. *Hot-sprayed Paint*	0·58	>11·9	0·51	> 9·9	0·48	> 9·7				
5. *Cement–Asbestos over:*										
a. Steel pickled by the sulphuric-acid/phosphoric-acid process	23·0	>11·9‡	21·4	>11·5	20·6	(>11·2)				
b. As *a*, with a priming coat of red lead in linseed-oil paint	20·1	>11·9‡	21·4	>11·5	23·4	>11·5				
c. As-rolled steel	21·5	>11·9‡	21·8	>11·5						
d. As *c*, with priming coat of red lead in linseed-oil paint	20·7	>11·9‡	23·3	>11·5						
C. OTHER COATINGS										
8. *Tar–Tallow–Lime, applied hot*	0·19	2·5	0·18	2·8						
9. *Vitreous Enamel*	4·09	>11·9	3·65	>11·5	3·64	>12·0§				
10. *Rubber–Wax Sheathing*	5·50	>11·9			5·47	8·2				

* The time given under the name of each site is the duration of exposure to the latest inspection. Each value represents the mean result for two specimens. Lives in brackets are approximate (*see* section on 'Methods of Inspection')

† Removed before the failure point

‡ One specimen only

§ Severely damaged by stones (up to 5% chipped and rusted), but no spread of rust from damage and no breakdown elsewhere

Table V

RESULTS OF SEA-IMMERSION TESTS (ZINC COATINGS)

2 years at Gosport, 4 years at Emsworth

Process	W, oz./sq. ft.	Final Observations		
		Loss in Weight, oz./sq. ft.	Discoloration and Rust-Staining,* %	Rust, %
Electrodeposited, cyanide bath	2·94	1·17	2	0·5
	2·84	1·12	25	0·5
Hot-dipped (firm A)	2·42	1·39	30	0·5
	2·59	1·26	40	—
Hot-dipped (firm B)	3·03	1·24	20	—
	3·05	1·30	20	0·1
Sprayed by molten-metal pistol	2·42	0·59	80	7·5
	1·30	1·43	80	20
Sprayed by powder pistol	4·01	0·24	80	1
	4·74	−0·23	25	—
Sprayed by wire pistol	1·79	0·80	60	—
	1·90	0·83	60	—

* Approximate only, because of difficulty in distinguishing between rust-stain and rust

the difference may justly be associated to some extent with the much smaller total film thickness, for it must be recognized that adequate paint-film thickness is essential for satisfactory protection.

The marked difference between the lives at Sheffield of painting scheme 1*e* over weathered steel (1·0 year) and over pickled steel (7·7 years) is a striking indication of the vital importance of correct surface preparation for painting. It is also decisive evidence that the inhibitive phosphoric-acid/chromic-acid wash forming part of this proprietary scheme was inadequate to counteract the damaging effects of allowing the steel to rust before painting it.

The priming paints in a lanolin medium, which contained zinc chromate as the essential pigment, proved inferior to red lead in linseed-oil priming paint at Llanwrtyd Wells (*see* Figs. 18–20) and Congella, where the average life of the two 4-coat painting schemes with lanolin priming paints was 4·4 and 5·4 years, respectively, but 7·3 and more than 6·6 years for the 4-coat scheme with a red-lead priming paint. At Sheffield the lives of all the three painting schemes concerned have exceeded the duration of exposure to date, 11·9 years: this is an excellent performance. The total dry-film thickness of these painting schemes based on a lanolin priming paint was roughly 5 mils and the same as for the comparison scheme based on red-lead paint:

Painting Scheme	Average Total Paint Weight, oz./sq.ft.	Paint Film Thickness, mils		
		2 Coats of Priming Paint	2 Coats of Red-Oxide Paint	Total
(*a*) Lanolin priming paint *A* (2 coats); red oxide in linseed-oil paint (2 coats)	0·61	1·9	2·7	4·6
(*b*) Lanolin priming paint *B* (2 coats); red oxide in linseed-oil paint (2 coats)	0·68	2·6	2·6	5·2
(*c*) Red lead in linseed-oil paint (2 coats); red oxide in linseed-oil paint (2 coats)	0·92	2·3	2·5	4·8

Hot-Sprayed Paint—Applied by the Pahl process this coating has done well (*see* Fig. 16), although it is doubtful whether its performance is significantly better than that of air-drying painting schemes of equal coating thickness.

Cement–Asbestos—The conditions of the specimens coated with sprayed cement–asbestos cannot be assessed with certainty, because it is impossible to see beneath the coating, but, so far as can be judged, this coating still remains effective at the three home

Table VI

LIVES OF METALLIC COATINGS WITHOUT AND WITH TWO COATS OF RED OXIDE IN LINSEED-OIL PAINT

Metallic Coating		Average Test Duration to Failure *L*, years*					
Metal and Process	Weight, oz./sq. ft.	Sheffield (11·9 years)			Llanwrtyd Wells (11·5 years)		
		Bare	Painted	Increase Due to Painting	Bare	Painted	Increase Due to Painting
Aluminium, cemented	0·6	2·0	>11·9	>9·9	0·1	>11·5	>11·4
Aluminium, sprayed by wire pistol	0·3	> 2·2	>11·9	c. 9·7	—	—	—
	0·7	>11·4	>11·9	c. 0·5	>11·5	>11·5	?
Zinc, cemented	0·6	2·0	7·9	5·9	> 9·4	>11·5	c. 2·1
Zinc, hot-dipped	1·0	3·0	8·5	5·5	—	—	—
	1·5	4·7	10·9	6·2	>11·5	>11·5	?
Zinc, sprayed by wire pistol	0·5	1·7	6·9	5·2	—	—	—
	1·5	3·6	>11·9	>8·3	>11·5	>11·5	?
Lead, electrodeposited	1·0	6·9	>11·9	>5·0	—	—	—
	2·9	>11·9	>11·9	?	>11·1	>11·5	c. 0·4
None†	—	—	6·8	—	—	>11·5	—

* The time given under the name of each site is the duration of exposure to the latest inspection. At Calshot (12·6 years) only zinc, cemented (0·5 oz./sq. ft.), was tested. This had lives of 8·8 years (bare) and >10·4 years (painted); difference >1·6 years. The life of the paint over bare steel (as below) was >10·4 years

† The steel was prepared for painting by pickling in sulphuric acid followed by immersion in hot dilute phosphoric acid

sites; it was not exposed overseas. In 1952, two specimens which had fallen from the stands at Llanwrtyd Wells because their suspension hooks had rusted through were brought back to the laboratory for examination. Each had lost 150 g. in weight during 11½ years' exposure. This is more than 10% of the coating weight and is probably due to erosion of the cement–asbestos by the rainwater. One specimen, which was sound, was returned to Llanwrtyd Wells for further exposure. The coating had cracked on the other specimen, and so the test was discontinued and the coating was stripped from the steel. Slight rusting was evident in places but no appreciable loss of metal had occurred; this specimen had been given a foundation coat of red lead in linseed-oil paint plus a coat of bituminous emulsion before the cement–asbestos was sprayed on.

The main problem in ensuring the successful use of coatings of this type seems to lie in preventing cracking and ingress of moisture at edges. Sprayed cement–asbestos and similar coatings are clearly more suitable for application to large flat surfaces than to a small specimen, such as that used in the present tests.

Tar–Tallow–Lime—When applied hot, this coating had only a short life (2–3 years), both at Sheffield and at Llanwrtyd Wells. Yet it is cheap and might prove effective and economical in practice if it were renewed at 2-yearly intervals until a substantial thickness had been built up.

Vitreous Enamel—This coating has given perfect protection up to 12 years, but it is vulnerable to damage.

Rubber–Wax Sheathing—This is another coating that protects steel merely by excluding the corrosive agent; the weak points are at the seams and edges. At Sheffield, so far as can be ascertained without stripping the coating, the rubber–wax sheathing has stood up for nearly 12 years, but it failed at Calshot after 8 years because of the ingress of rainwater (*see* Fig. 17).

Sea-Immersion Tests

At the end of 6 years' immersion in sea water, the coatings on the remaining specimens showed signs of breakdown (*see* Table V). They were all of zinc and were found to be in passable condition after cleaning. The electrodeposited and hot-dipped coatings were still intact over at least 80% of the surface; the corresponding figures for sprayed coatings were about 10% for the molten-metal pistol and 50% for both the powder and the wire pistols. These and similar differences shown in Table V should be attributed to differences in the coating weights rather than in the processes of application. Visual inspection showed that the electrodeposited and hot-dipped coatings, weighing roughly 3 oz./sq. ft., had just ceased to give complete protection to the steel.

The main conclusion from the sea-immersion tests is, therefore, that zinc coatings weighing 3 oz./sq. ft., *i.e.*, about 0·005 in. thick, will protect steel for about 6 years under these conditions. The consumption of zinc is roughly 0·5 oz./sq. ft. of steel surface protected per year. The tests have also shown that zinc coatings are superior to coatings of aluminium, cadmium, lead, or tin for protecting steel against corrosion in sea water, since all the specimens coated with any of the last four metals were removed from test after 2 years because of failure.

CONCLUSIONS

(1) The protective value of aluminium, cadmium, and zinc coatings on steel is roughly proportional to the coating thickness. There is no marked difference in the performance of zinc coatings applied by different processes but of equal weight.

(2) Metallic coatings give excellent protection against atmospheric corrosion. In an industrial atmosphere, such as Sheffield, flat steel surfaces can be protected against rusting for 10 years by a coating of sprayed aluminium weighing about ¾ oz./sq. ft., by a zinc coating weighing about 3 oz./sq. ft., or by a lead coating weighing about 3 oz./sq. ft. These coating weights correspond to coating thicknesses of 3 mils for aluminium and lead, or 5 mils for zinc.

(3) Lead coatings are less serviceable in rural and marine atmospheres than in industrial atmospheres, where they are protected by the formation of a surface film of sulphate.

(4) In an industrial atmosphere, aluminium coatings protect steel against general corrosion rather better than zinc coatings of equal thickness. For practical purposes, however, some attention should be paid to the greater cathodic protection yielded by zinc at sharp edges.

(5) In an industrial atmosphere, cadmium coatings are inferior to zinc coatings of equal thickness. At Sheffield the life of an electrodeposited coating, 3 mils thick, was about 2 years for cadmium, but it was 6 years for zinc.

(6) The performance of red oxide in linseed-oil paint is better when applied over lead or aluminium coatings than over zinc coatings.

(7) Priming paints in a lanolin medium give moderate results and are inferior to red lead in linseed-oil priming paint.

(8) A tar–tallow–lime coating applied hot protects steel only for about 2–3 years in an industrial atmosphere, compared with 7 years or more for the best painting schemes. For some purposes, however, the tar coating might prove effective and economical if renewed at sufficiently frequent intervals.

(9) Hot-sprayed paint applied by the Pahl process protects steel well in the atmosphere, but probably no better than a well-applied system of air-drying paints.

(10) Vitreous enamel is an excellent protection for steel if mechanical damage can be avoided. The enamel itself was not appreciably affected by 12 years' exposure at Sheffield.

(11) Coatings such as rubber–wax sheathing or sprayed cement–asbestos depend for their efficiency on freedom from cracking or damage and on the tightness of the seams at the edges. When these conditions are satisfied they have a long life in the

atmosphere. For example, most of the specimens coated with cement–asbestos were in good condition for up to 12 years.

(12) Of the metal coatings tested, zinc is the best for protecting steel immersed in the sea; 3 oz./sq. ft. will prevent serious rusting for about 6 years.

Acknowledgments

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References

1. J. C. Hudson and T. A. Banfield: *J. Iron Steel Inst.*, 1946, No. 2, pp. 229P–264P.
2. J. C. Hudson and T. A. Banfield: *Ibid.*, 1948, vol. 158, pp. 99–110.
3. Marine Corrosion Sub-Committee: *Ibid.*, 1943, No. I, p. 399P.
4. P. T. Gilbert: *J. Appl. Chem.*, 1953, vol. 3, pp. 174–181.
5. S. E. Hadden: *J. Iron Steel Inst.*, 1952, vol. 171, pp. 121–127.
6. Second Interim Report of Joint Technical Panel J/P1, p. 11: 1949, London, B.I.S.R.A.

Further Correspondence on the Paper—

TRANSGRANULAR STRESS CORROSION IN CHROMIUM–NICKEL STAINLESS STEELS*

By C. Edeleanu

Mr. **J. J. Heger** and Mr. **E. J. Dulis** (United States Steel Corporation) wrote : The data presented by Dr. Edeleanu do not completely support his theory that transgranular stress-corrosion cracking in the austenitic stainless steels is associated with the formation of ' quasi-martensite '. For example, in Table I of his paper a steel containing 24% of chromium and 21% of nickel, captioned as 25/20 steel, failed after 28 hr. Although the time to failure for this steel was much greater than for other steels included in Table I, we think that the evidence that this steel will fail by stress corrosion casts some doubt on the author's theory, because we do not believe that quasi-martensite will form in a 25/20 steel. Support for our belief is found in a paper by Post and Eberly,[1] in which it was shown that samples of a 25/20 steel could be cold-worked quite drastically and still show no evidence of formation of a magnetic quasi-martensite phase.

Another steel that shows a susceptibility to stress-corrosion cracking is the 18/18 Mo–Cu steel also appearing in Table I. This steel contains 17·88% Cr and 17·80% Ni, together with 4% Mo and 2·50% Cu. It does not seem likely that this steel would form quasi-martensite when it is strained, yet it is susceptible to stress-corrosion cracking.

Further evidence of stress-corrosion cracking in a steel that does not contain quasi-martensite is given by a 25/12 Cr–Ni steel that had been exposed to molten sodium hydroxide at 700° F. (*see* Fig. *A*). Evidence that magnetic quasi-martensite would not form in a steel of this type was given by Austin and Miller,[2] who showed that 25/12 Cr–Ni steel cold-reduced up to 90% exhibited no change in magnetic permeability.

Because of the significant exceptions to the author's proposed hypothesis, we are inclined not to accept the explanation that transgranular stress-corrosion cracking in austenitic stainless steels is caused by quasi-martensite. Any theory that is to explain such cracking in austenitic stainless steels must be capable of explaining all transgranular stress-corrosion failures in these steels.

Mr. **H. Nathorst** (The Sandvik Steelworks Ltd., Sweden) wrote : Dr. Edeleanu has taken up the suggestion made by Rocha that the γ–α transformation should play a fundamental rôle in the mechanism of stress-corrosion cracking of stainless austenitic steels. On that basis Dr. Edeleanu has proposed a detailed hypothesis, according to which the explanation of the sensitivity to stress-corrosion cracking, characteristic of austenitic stainless steels, should be that :

(i) The stress causes a certain amount of martensite formation in the stressed austenite
(ii) The formed martensite plates are preferentially attacked, the attack taking the form of narrow cracks
(iii) The necessary yielding for forming martensite is caused either by corrosion of an adjacent plate of martensite or by ' weakening due to ordinary corrosion of austenite '

* *J. Iron Steel Inst.*, 1953, vol. 173, Feb., pp. 140–146. For previous correspondence *see* vol. 174, July, p. 218.

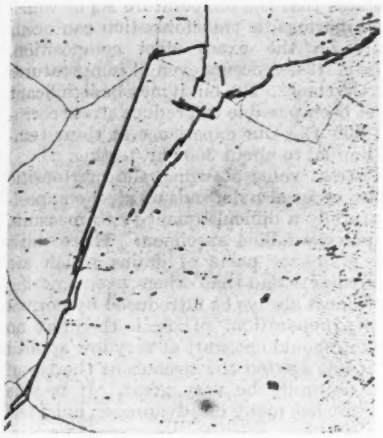

Fig. A—Transgranular stress-corrosion crack in a $\frac{5}{8}$-in. plate removed from a 25% Cr–12% Ni kettle used to hold molten sodium hydroxide at 700° F.

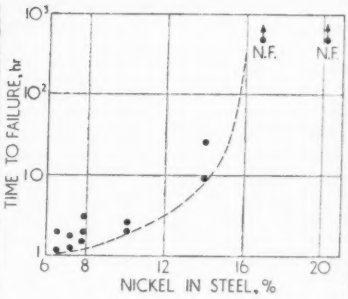

Fig. B—Effect of nickel content on time to failure of 18% Cr, 0·07–0·05% C steels

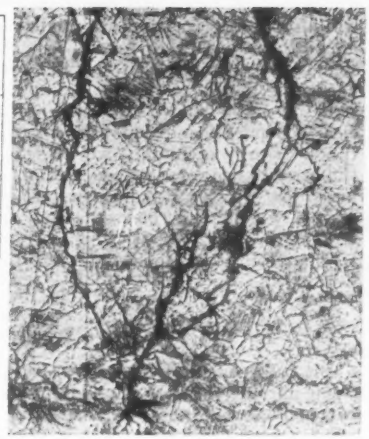

Fig. C—Stress-corrosion cracking in a highly susceptible steel × 200

(iv) The martensite is tempered at the temperature used in the test, this tempering lowering its corrosion resistance.

Dr. Edeleanu states (p. 145) that " There seems little doubt that this particular type of stress corrosion is connected with the attack on quasi-martensite . . .", but it may be questioned whether the evidence given in his paper is sufficient to support a statement of such a general nature. He has shown that if austenite containing a certain amount of martensite is exposed in a stressed condition to boiling $MgCl_2$ solution the martensite will be attacked preferentially, and this may serve as evidence for the second part of his theory, as outlined above. However, no evidence is produced to support the first part of his theory, *viz.*, that the stress causes a certain amount of martensite formation, and it may be of interest to compare it with some recent findings about martensite formation in stressed austenite in 18/8 steels. In his introduction Dr. Edeleanu states that the stresses necessary to cause stress-corrosion cracking are low, and he quotes one report that puts it below 10,000 lb./sq. in. and possibly as low as 3000 lb./sq. in. Investigations in Sweden[3] have in one case given a threshold value of about 6700 lb./sq. in. (This value was determined on a niobium-stabilized 18/8 steel in a carefully stress-relieved condition, tested in 36% $CaCl_2$ solution at 100° C., with the test specimens stressed in bending by a loading device giving constant bending moment over a certain length.) Angel[4] has recently shown that, relatively independent of temperature, a true stress of about 70,000 lb./sq. in. is needed to start martensite formation in the austenite of 18/8 steels. Moreover, at a temperature of about 50° C. this value of true stress already corresponds to 30–40% true strain, and at 154° C. (the boiling temperature of a 42% $MgCl_2$ solution) no amount of strain can start martensite formation.

From the above facts it may be concluded that stress-corrosion cracking can occur at stresses far below the minimum needed for formation of martensite,* and that the proposed mechanism of a crack growing as a result of new martensite formation near the edge of the crack is improbable at the temperature used in the experiments.

It may therefore be said that no martensite will form in the stress range most used in practice, so that there will be no possibilities for preferential attack of martensite plates. It may well be that Dr. Edeleanu's explanation can be applied to special cases, but in my opinion it does not cover the entire field, nor even the more important part of it.

If the theory of the connection between stress-corrosion cracking and γ–α transformation were correct, how could steel 25/20 (Table I), which is a very stable alloy, be at all sensitive to stress-corrosion cracking ? (' Stable ' means here that the austenite is stable against martensite transformation, the stability being characterized by a low value of M_s temperature, calculated according to Eichelman and Hull.[5])

It is regrettable that the U-bend specimen is still used to such an extent for research on the nature and mechanism of stress-corrosion cracking. It is quite true, as Dr. Edeleanu states, that the main advantage of the U-bend specimen " is the possibility of carrying out large numbers of experiments with simple equipment in a relatively short time," but this advantage seems to be of doubtful value if one considers the disadvantages of the test.[6] In the first place, the steel is tested in a severely cold-worked condition. A survey of practical experience[7] shows clearly that many cases of stress-corrosion cracking occur in parts which have been annealed after the last severe cold-working. Bearing in mind the instability of austenite, it is obvious that the U-bend specimens will sometimes show a structure consisting of austenite containing a certain amount of martensite, the amount varying across the thickness. It can be questioned whether the observed corrosion resistance of a steel in this state of microstructure does correlate with the corrosion resistance of the same steel in its proper microstructural state, the homogeneous austenitic state.

In the second place, the stress system in the U-bend specimen is fairly complicated and—because of relaxation—not constant with time. Thirdly, it has recently been shown by Logan[8] that the electrochemical potential is influenced by the applied stress. Thus, a type of specimen in which the stresses vary along the length of

* It is known that certain crystals in the surface layer will yield at a much lower stress than the bulk, and thus it may be possible that martensite formation will start at a lower true stress than the 70,000 lb./sq. in. mentioned. Even assuming that the critical stress for the surface is only half of the bulk value, there is a considerable difference between 35,000 and 6700 lb./sq. in.

the specimen (*e.g.*, *see* Nathorst, *loc. cit.*,[6] Fig. 11) will also be electrochemically undefined.

In other words, the U-bend test is one in which the steel is tested after a relatively unknown degree of work-hardening, in a relatively unknown state of microstructure, and under relatively unknown stress and electrochemical conditions (the two latter varying with time). In my opinion, if we wish to know more about the mechanism of stress-corrosion cracking of steels under low stresses, it is necessary to test the steel in the state in which it is to be used, under known and constant stresses within the elastic (or nearly elastic) range, and to change the criterion from ' time to failure ' to threshold stress values.

AUTHOR'S REPLY

Dr. **C. Edeleanu** (Brown-Firth Research Laboratories) wrote in reply : Mr. Heger and Mr. Dulis raise an interesting point. The steels 25/20, 25/12, and 18/18 Mo–Cu which they mention are (as the work of Post and Eberly predicts) stable, and there is no evidence that such steels transform during cold-work. Thus, no significant difference was found in the magnetization per gramme of cold-worked and soft samples of a 25/20 alloy, although the Sucksmith magnetic balance[9] used for these determinations was capable of detecting about 0·02% of ferro-magnetic phase in 18/8 alloy.

In view of this fact, and since these steels, although relatively resistant to stress corrosion, are still slightly susceptible, it is quite possible that the original theory does not fully cover the position. Nevertheless, we still consider that the idea expressed forms a useful working theory, even though some extension may be required.

Some further results which support this view are given in Fig. *B*, which shows the time to failure of various steels containing nominally 18% of chromium and 0·07–0·05% of carbon, and tested in the $MgCl_2$ solution under an applied stress of 20 tons/sq. in. These results show that an increase in nickel, as might be expected from the theory, is effective in preventing stress corrosion, and the discrepancy with Post and Eberly's work is only that this increase has occurred at a slightly higher nickel level (2–3% Ni) than might have been expected. Similar results have been obtained with steels containing Nb, Ti, and Mo, but the decrease in susceptibility in these cases occurs at somewhat lower nickel values. Carbon, as might be expected from Post and Eberly's work, has also proved to be effective in preventing stress corrosion under present test conditions, but it is naturally not a practicable addition to make to stainless steels.

There are two possible explanations for the discrepancy between the magnetic and stress-corrosion work : either stress corrosion can occur when the martensite plates are so few and those present so thin that magnetic detection is difficult, or all that might be necessary for stress corrosion is a tendency to martensitic transformation, without this actually taking place. A similar situation exists in the case of stress corrosion of light alloys, in which it is generally agreed that stress corrosion is associated with changes occurring at the grain boundaries as a result of ageing; but here again there are cases where stress corrosion results when these changes have occurred only to such a slight extent that it is difficult to detect them by the usual metallurgical means.

It must be pointed out that so little is known about the fundamental processes involved in stress corrosion (which, as shown in the paper, can occur in many alloy systems) that all present explanations must be regarded as tentative.

In reply to Mr. Nathorst, the effect of strain and temperature on the martensitic transformation is discussed by Cina,[10] who states that the temperature M_d at which the stress-induced martensitic transformation can occur depends critically on the exact steel composition. Admittedly, stress corrosion occurs even at temperatures above M_d (*e.g.*, in the steel 25/20), but it may be significant that it has not yet been possible to produce stress corrosion in steam at 600° C. Our experience at these temperatures is still limited to about 3000 hr. testing.

The threshold stress value at which the martensitic transformation can occur also depends on steel composition, but it is naturally a difficult quantity to measure, especially in a polycrystalline specimen. There must always be some grains or parts of grains which are strained to a far greater extent than others, even ignoring the stresses which must always be introduced by normal methods of sample preparation. There is therefore no reason why cracking should not start at very low applied loads, and once it has started the stresses at the tip of the crack would naturally be very great. It is true that the U-bend test has many disadvantages, but I feel that it is just as difficult to calculate the stress in a partially cracked polycrystalline tensile specimen as in a U-bend test.

For the past two years I have used a tensile test mainly because, in each test, times to failure can be measured and do not involve frequent observations. Although this type of test looks more scientific than the U-bend test, it has most of the fundamental disadvantages of the simple test and the great disadvantage of being less severe.

So far as the practical side of the question is concerned, most failures I have examined have occurred in steels which were abnormally susceptible to martensitic transformation. The analyses of such steels have sometimes been within the normal range. The easiest test for high susceptibility to martensitic transformation is the examination of hand-polished sections after heavy etching. If such specimens give an uneven appearance, such as that shown in Fig. *C*, which is an actual service case, the steel is very likely to be highly susceptible both to martensitic transformation and to stress corrosion. On electropolishing, such steels give normal austenitic structures with generally a few martensitic plates.

Finally, I wish to emphasize that a threshold stress determined in the laboratory should not be used for design purposes. Naturally, the lower the stress the greater the safety, but high stresses can arise very locally in structures which on paper look almost stress-free, for the reasons stated above. For this reason I think that the threshold stress, even if it could be determined with accuracy, which I doubt, would not be of much practical use.

REFERENCES

1. C. B. Post and W. S. Eberly : *Trans. Amer. Soc. Metals*, 1947, vol. 39, pp. 868–890.
2. J. B. Austin and D. S. Miller : *Ibid.*, 1940, vol. 28, pp. 743–755.
3. Committee for Stress-Corrosion Cracking in Stainless Steels, Jernkontoret : Unpublished results.
4. T. Angel : To be published.
5. G. H. Eichelman, jun., and F. C. Hull : *Trans. Amer. Soc. Metals*, 1953, vol. 45, pp. 77–95.
6. H. Nathorst : Welding Research Council Bulletin Series, 1950, Oct., No. 6, p. 11.
7. H. Nathorst : *Ibid.*, p. 1.
8. H. L. Logan : *Corrosion*, 1952, vol. 8, June, p. 16 ; *J. Res. Nat. Bur. Stand.*, 1952, vol. 48, pp. 99–105.
9. W. Sucksmith : *Proc. Roy. Soc.*, 1939, vol. 170, Ser. A, pp. 551–560.
10. B. Cina : To be published.

Activities of Constituents of Iron and Steelmaking Slags

By E. T. Turkdogan, Ph.D., M.Met., and J. Pearson, Ph.D., M.Sc., F.R.I.C.

PART II—MANGANOUS OXIDE

SYNOPSIS

The equilibrium constant of the manganese reaction has been calculated and used, in conjunction with the ferrous oxide activity diagram from Part I, to evaluate the activity of manganous oxide in MnO–FeO–SiO_2 and some basic steelmaking slags. Temperature appears to have no influence on the activity of manganous oxide in a slag of given composition. Variations in activity have been related to slag composition, and iso-activity curves have been drawn for the MnO–FeO–SiO_2 system and for some pseudo-ternary (CaO + MgO)–MnO–(SiO_2 + P_2O_5) systems containing fixed proportions of ferrous oxide. The use of these curves for calculating manganese content of metal and manganous oxide content of slags is illustrated. 819

MUCH experimental work has been reported on the manganese reaction in steel refining, but the different methods of interpretation have led the various authors to conflicting conclusions. In general, results have been presented as an equilibrium ratio defined by

$$K'_{Mn} = \frac{(MnO)}{(FeO)\,[Mn]},$$

where (MnO) and (FeO) are concentrations in the slag and [Mn] is the concentration of manganese in the metal. The equilibrium ratio was found to vary with the composition and temperature of the slag, but no systematic study has been made to evaluate this variation of K'_{Mn}; slags have been merely classified as acid or basic and appropriate values of K'_{Mn} suggested. It is clear, therefore, that a knowledge of how the equilibrium ratio varies over a wide range of slag composition would be of value.

It is, however, more logical to assume that the equilibrium ratio, at any given temperature, determined with pure FeO–MnO slags remains constant in other systems and that additions of silica, lime, etc., affect the activities of both MnO and FeO and so change K'_{Mn}. Part I[1] gives a ternary diagram from which may be read the activities of ferrous oxide in slags of various compositions. If similar diagrams were available for manganous oxide, it would be possible to calculate either the manganese oxide content of a slag in equilibrium with a steel of known manganese content or, alternatively, the manganese content of a steel in equilibrium with a given slag. The present paper attempts to produce such diagrams.

The early work on the manganese reaction has been reviewed by Chipman,[2] and since then only a few results specifically related to this subject have become available.[3, 4]

THE EQUILIBRIUM CONSTANT K_{Mn}

The equilibrium constant of the reaction

$$FeO\ (in\ slag) + \underline{Mn} \rightleftharpoons MnO\ (in\ slag) + \underline{Fe} \quad \ldots(1)$$

may be written

$$K_{Mn} = \frac{(a_{MnO})}{(a_{FeO})\,[a_{Mn}]} \quad \ldots\ldots\ldots\ldots\ldots(2)$$

because the activity of iron is not likely to change significantly with variations in manganese content. Since liquid manganese and iron oxides behave ideally when mixed together and the same is true for solutions of manganese in iron, at least at low concentrations, equation (2) may be rewritten

$$K_{Mn} = \frac{(N_{MnO})}{(N_{FeO})\,[Mn\%]}, \quad \ldots\ldots\ldots\ldots\ldots(3)$$

where (N_{MnO}) and (N_{FeO}) signify mole fractions of MnO and FeO in the binary slag and [Mn%] is the weight concentration of manganese in the metal.

In the experiments conducted by Chipman, Gero, and Winkler,[3] essentially pure FeO–MnO slags were used, the impurities being, for example, 0·03–0·10 mole fraction of (CaO + MgO) and 0·01–0·05 mole fraction of SiO_2. It can be assumed that these impurities had no effect on the ideal behaviour of the iron and manganese oxides, for not only is the scatter of the results normal for experiments of this type, but it cannot be correlated with variations in nature of the impurities. Larger proportions of impurities have a noticeable effect on the activities of the oxides, for the slags employed by Körber and Oelsen,[5] which contained higher concentrations of MgO than those of Chipman and his co-workers,[3] gave rise to lower K_{Mn} values.

Although it appears correct to use the data of Chipman, Gero, and Winkler to evaluate K_{Mn} as a function of temperature, their method of deriving a mathematical relationship between log K_{Mn} and $1/T$ appears to be open to some criticism. They calculated the free-energy change in reaction (1) from existing thermal data and an estimated heat of fusion for manganous oxide, and then drew a line through their

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Dr. Pearson is Head of the Chemistry Department and Dr. Turkdogan is Head of the Physical Chemistry Section of the Chemistry Department of the Association.

Table I

EFFECT OF SLAG COMPOSITION

N_{MnO}	N_{FeO}	$N_{CaO}+N_{MgO}$	$N_{SiO_2}+N_{P_2O_5}$	a_{MnO}	Temp., °C.
0·11	0·05	0·61	0·23	0·30	1640
0·11	0·05	0·61	0·23	0·30	1750
0·07	0·10	0·52	0·31	0·11	1550
0·07	0·10	0·52	0·31	0·12	1590
0·07	0·10	0·52	0·31	0·11	1615
0·07	0·10	0·66	0·17	0·20	1650
0·07	0·10	0·66	0·17	0·21	1690
0·05	0·15	0·63	0·17	0·22	1657
0·05	0·15	0·63	0·17	0·20	1700

experimental points but parallel to the calculated line. The possible errors in their estimate are so great as to make the slope of the calculated line no more reliable than that derived from their experimental points. For this reason, the equation

$$\log K_{Mn} = \frac{7406}{T} - 3{\cdot}436 \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

derived statistically from the results of Chipman and his co-workers will be used in this paper to calculate the value of K_{Mn} at any temperature.

ACTIVITY OF MANGANOUS OXIDE

The activity of manganous oxide in a slag can be calculated from the equation

$$a_{MnO} = K_{Mn}\,(a_{FeO})\,[Mn\%], \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where K_{Mn} is the manganese constant calculated for any temperature from equation (4), a_{FeO} is the activity of ferrous oxide derived from the ternary diagram,[1] and [Mn%] is the concentration of manganese in the metal phase. It is assumed that the presence of other materials (carbon, oxygen, phosphorus, etc.) dissolved in the iron does not materially affect the behaviour of dissolved manganese. Maurer and Bischof[6] suggest that increasing proportions of dissolved phosphorus reduce the value of K'_{Mn}, *i.e.*, that phosphorus reduces the activity of manganese in iron. This conclusion has not been verified by recent work.[7] The results of Maurer and Bischof are therefore not used in this paper.

When a slag composition is such that a_{FeO} cannot be derived from the iso-activity diagram,[1] the activity can often be calculated from the oxygen content of the liquid iron, provided that there is not a high concentration of alloying elements which would affect the activity of oxygen in the metal. In such a case, $a_{FeO} = [O\%]/L_{FeO}$, where

$$\log L_{FeO} = -\frac{6320}{T} + 2{\cdot}734, \quad \ldots\ldots\ldots(6)^{8}$$

and then

$$a_{MnO} = \frac{K_{Mn}\,[O\%]\,[Mn\%]}{L_{FeO}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Although the activity coefficient of a component in a non-ideal solution would be expected to be temperature-dependent, examination of experimental data indicates that the activity coefficient of MnO, like that of FeO,[1] is independent of temperature. This may be due to lack of sufficient data or to the difficulty of evaluating the effects of all possible variables; nevertheless, from a practical viewpoint it can be assumed that the activity of MnO depends only on slag composition. This is illustrated in Table I, where the values have been taken from published results on complex slags.[7, 9, 10]

Although it is not possible to investigate the effects of all the separate constituents of a slag on the activity of MnO, it is possible to consider the influence of $(CaO + MgO)$, FeO, and $(SiO_2 + P_2O_5)$. It appears that the effects on the activity of MnO of lime and magnesia are equivalent; the same is true for silica and phosphorus pentoxide, at least up to 0·1 mole fraction of the latter (which is the maximum content in the slags under consideration). It should be noted that the considerations in this paper, as well as those in Part I, will not be applicable when larger concentrations of phosphorus pentoxide are present. The presence of such quantities of P_2O_5 in a $CaO–FeO–SiO_2$ slag leads to the appearance of a two-phase system, and the FeO iso-activity curves will then not have the shape previously reported. In addition, the influence of dissolved alumina cannot be predicted, because those slags which were used to construct the FeO activity curves contained less than 0·005 mole fraction of Al_2O_3.

FeO–MnO–SiO_2 Slags

Experimental results on slags of this system have been obtained by Schenck[11] and by Körber and Oelsen.[12] The latter authors studied the manganese–silica reaction mainly under silica-saturated slags, but some of their slags were not saturated with silica, as can be seen from a comparison of their slag compositions with the FeO–MnO–SiO_2 ternary phase diagram. Furthermore, in silica-saturated slags it is the composition of the liquid phase, and not the gross composition, which governs the activity of manganous oxide. The compositions of the liquid phase in these slags have been calculated with the aid of the ternary phase diagram and used to evaluate activity–composition relationships.

In Fig. 1, the activity of manganous oxide is plotted against its concentration in the ternary solution at the following silica contents: $N_{SiO_2} = 0{\cdot}45 \pm 0{\cdot}005$,

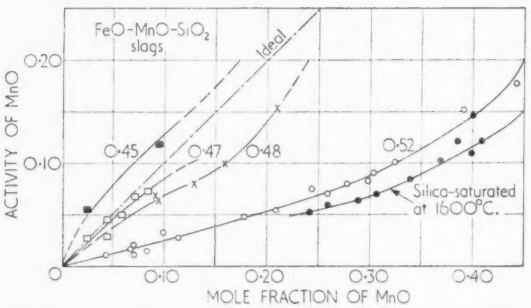


Fig. 1—Activity of manganous oxide in FeO–MnO–SiO_2 slags

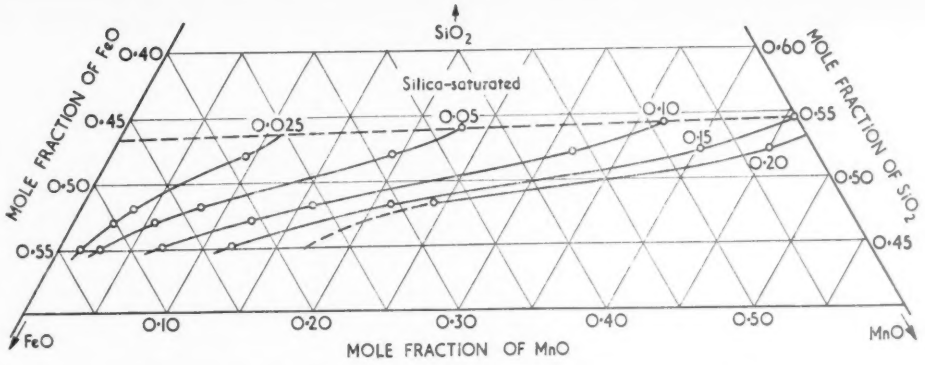


Fig. 2—Manganous oxide iso-activity curves in some FeO–MnO–SiO_2 slags

$0{\cdot}47 \pm 0{\cdot}005$, $0{\cdot}48 \pm 0{\cdot}005$, $0{\cdot}52 \pm 0{\cdot}01$, and saturation. The curves hold for any temperature within the range of the experiments, except that for silica saturation, where the compositions were obtained from the 1600° C. silica solubility isothermal. Figure 2, derived from Fig. 1, is a more useful form, showing MnO iso-activity curves on a portion of the ternary diagram. The curves cannot be extrapolated beyond 0·45 mole fraction of silica without introducing errors of unknown magnitude, because these iso-activity curves have inflexion points like those found for ferrous oxide.[1]

When Fig. 2 is compared with the ferrous oxide iso-activity diagram, it is seen that increasing silica concentration reduces the activity of manganous oxide to a much greater extent than that of ferrous oxide; this is attributed primarily to the greater stability of manganese silicates as compared with the ferrous silicates.

(CaO + MgO)–FeO–MnO–(SiO_2 + P_2O_5) Slags

Information used in the consideration of this system was drawn from the work of Schenck,[9] Winkler and Chipman,[7] and Harders, Grewe, and Oelsen.[10] Schenck and Oelsen and his co-workers had obtained results from open-hearth heats, and Chipman studied laboratory melts.

This quaternary system may be studied by taking ternary sections at different ferrous oxide concentrations. In these considerations the total iron in the slags was calculated as FeO (*see* Part I[1]). The available data permit the examination of three such sections, at 0·05, 0·10, and 0·20 mole fraction of FeO. The variations in composition are such as to cover slags of interest in basic steelmaking practice.

In Fig. 3, the activity of MnO is plotted against its concentration for various values of N_B (the sum of the mole fractions of CaO and MgO) at each of the above concentrations of FeO. In all instances the activity of MnO shows a positive deviation from ideal behaviour. By reading from these curves the compositions corresponding to certain definite activities of MnO, it is possible to derive iso-activity curves as functions of composition at each of the three FeO levels (*see* Fig. 4). The iso-activity curves in Fig. 4*a* exhibit an inflexion at about $N_B = 0{\cdot}53$, whereas when $N_{FeO} = 0{\cdot}10$ and $0{\cdot}20$ the inflexion points probably lie at values of N_B greater than 0·65. Because of lack of data it is not possible to extend these iso-activity curves.

DISCUSSION

Figures 3 and 4 indicate that, although the activity of manganous oxide in a slag of given composition is essentially independent of temperature, the activity for a given proportion of MnO is markedly dependent on the relative concentrations of (CaO + MgO), FeO, and (SiO_2 + P_2O_5), and that consequently the classification of slags into acid and basic types for assigning values of K_{Mn} is far from adequate.

To interpolate the iso-activity curves to any iron oxide content the following method may be used. The values of N_B, N_{MnO}, and N_{FeO} are calculated for the slag under consideration. From Figs. 4*a–c*, the activity of MnO corresponding to the calculated values of N_B and N_{MnO} are read off and plotted against the values of N_{FeO} of 0·05, 0·10, and 0·20. From the resulting curve the value of the activity of MnO corresponding to the FeO content of the slag may be determined. Some typical curves drawn in this way are shown in Fig. 5. The two points at $N_{FeO} = 0{\cdot}28$ have been derived from results of some open-hearth trials carried out by the staff of B.I.S.R.A. in collaboration with Messrs. John Summers and Sons Ltd., Shotton.

The curves in Fig. 5 show that, in general, an increase in iron oxide content at given values of N_B and N_{MnO}, and thus a decrease in the content of (SiO_2 + P_2O_5), lowers the activity of MnO, although with slags that have a higher value of N_B initial additions of FeO increase the activity of MnO. The effect of FeO becomes less as the MnO content falls; *i.e.*, when the concentration of MnO is small its activity coefficient is almost independent of the relative proportions of FeO and SiO_2.

It would be of interest to evaluate the activity of MnO in the binary CaO–MnO and MnO–SiO_2 systems or possibly in the pseudo-binaries (CaO + MgO)–MnO and MnO–(SiO_2 + P_2O_5), but lack of data prevents any extrapolation of the iso-activity lines in Figs. 4*a–c* to the binary sides of the diagrams. It seems clear, therefore, that the method employed by Bell, Murad, and Carter[4] must be regarded with suspicion, since they have failed to take into consideration the

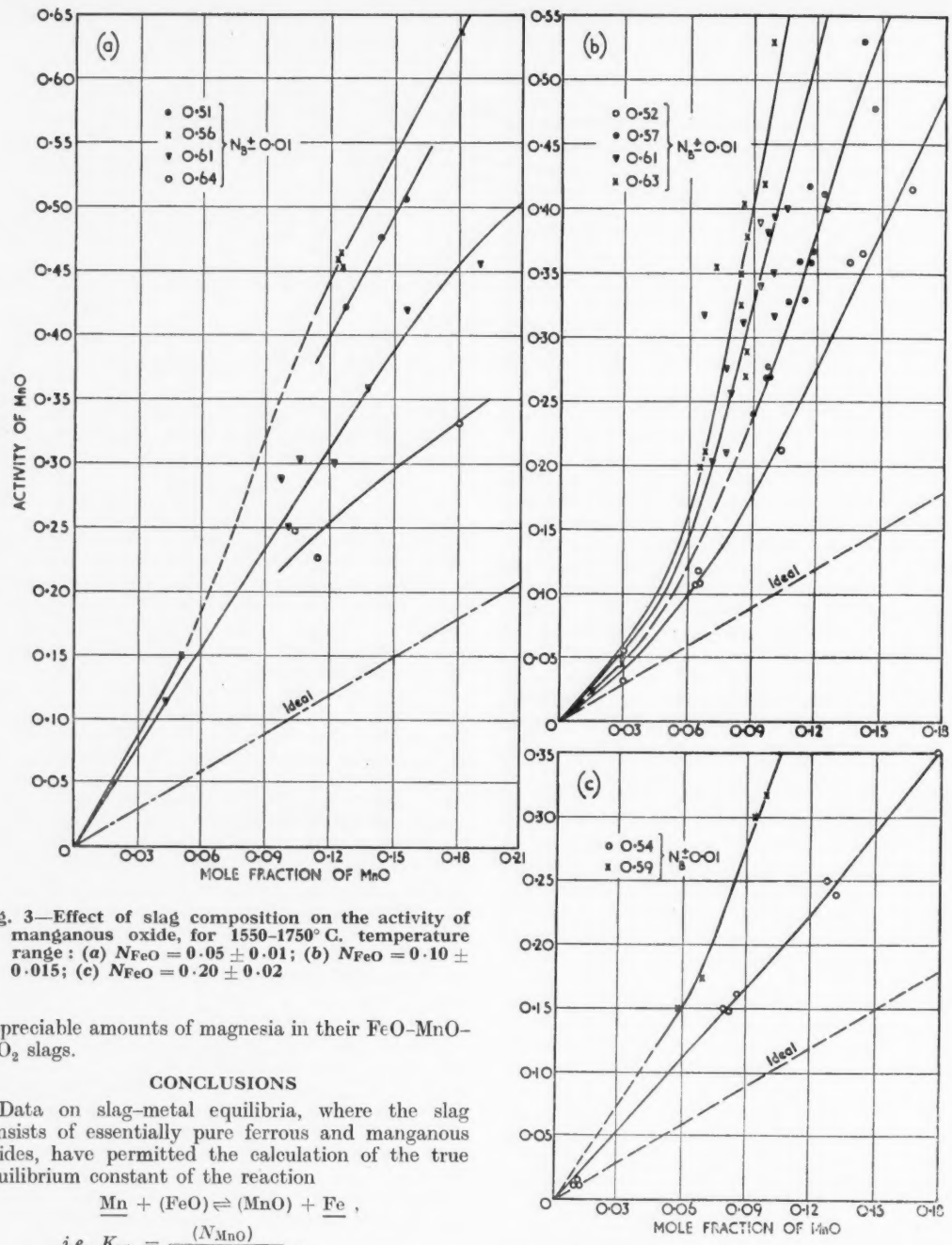


Fig. 3—Effect of slag composition on the activity of manganous oxide, for 1550–1750° C. temperature range: (*a*) $N_{FeO} = 0·05 \pm 0·01$; (*b*) $N_{FeO} = 0·10 \pm 0·015$; (*c*) $N_{FeO} = 0·20 \pm 0·02$

appreciable amounts of magnesia in their FeO–MnO–SiO_2 slags.

CONCLUSIONS

Data on slag–metal equilibria, where the slag consists of essentially pure ferrous and manganous oxides, have permitted the calculation of the true equilibrium constant of the reaction

$$\underline{Mn} + (FeO) \rightleftharpoons (MnO) + \underline{Fe} ,$$

$$i.e., K_{Mn} = \frac{(N_{MnO})}{(N_{FeO})\,[Mn\,\%]} .$$

This was found to be

$$\log K_{Mn} = \frac{7406}{T} - 3·436,$$

which is in fair agreement with the calculated free-energy change in the reaction.

The variation of activity of manganous oxide has been related to the composition of steelmaking slags. In FeO–MnO–SiO_2 slags, rich in silica, manganous oxide activity shows a negative deviation from ideality, the extent of which is greater than that found for FeO; this is attributed to the greater stability of manganese silicates.

More complex slags have been divided into groups of fixed ferrous oxide content, and MnO iso-activity diagrams have been drawn for three pseudo-ternary

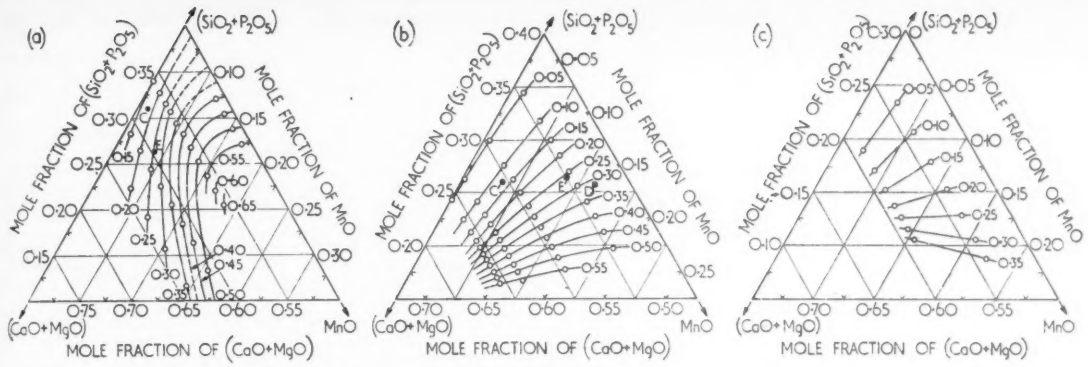


Fig. 4—Manganous oxide iso-activity curves for 1550–1750° C.: (*a*) $N_{FeO} = 0{\cdot}05 \pm 0{\cdot}01$; (*b*) $N_{FeO} = 0{\cdot}10 \pm 0{\cdot}015$; (*c*) $N_{FeO} = 0{\cdot}20 \pm 0{\cdot}02$

$(CaO + MgO)$–MnO–$(SiO_2 + P_2O_5)$ systems. Sections through these diagrams indicate that, in general, increasing the iron oxide concentration reduces the activity of manganous oxide. Temperature appears to be without influence on the activity of MnO, and the diagrams may be applied to slags at temperatures between 1550° and 1750° C., the usual range for steelmaking operations. The use of the diagrams is illustrated in the Appendix.

APPENDIX

Application of the Activity Diagrams

To Determine the Manganese Content of Metal in Equilibrium with a Slag of Known Composition

Let the slag have a composition denoted by $N_{(CaO+MgO)} = 0{\cdot}58$, $N_{FeO} = 0{\cdot}07$, and $N_{MnO} = 0{\cdot}06$, balance $(SiO_2 + P_2O_5)$, and let the temperature of the system be 1620° C. (1893° K.). Since $N_{FeO} = 0{\cdot}07$, Figs. 4*a* and *b* must be used. When the values $N_{(CaO + MgO)} = 0{\cdot}58$ and $N_{MnO} = 0{\cdot}06$ are plotted on Fig. 4*a*, the activity of MnO is seen to be 0·18 (*see* point *C*). When they are plotted on Fig. 4*b*, the activity of MnO is shown to be 0·13 (*see* point *C'*).

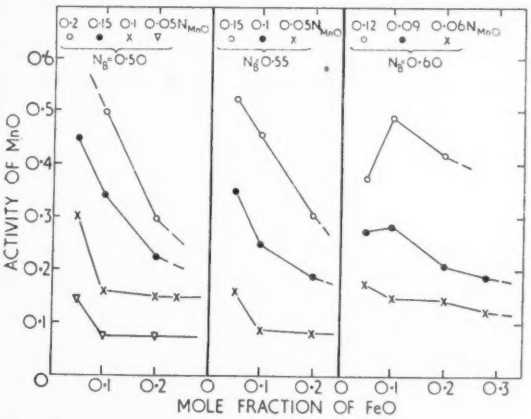


Fig. 5—Effect of ferrous oxide concentration on the activity of manganous oxide at various slag compositions

Figure 5 indicates that it is adequate to interpolate linearly between these two values, and thus for $N_{FeO} = 0{\cdot}07$ the activity of MnO is 0·16. The activity of FeO in a slag of the above composition is 0·34 (*see* the FeO iso-activity diagram[1]). The value of K_{Mn} at 1893° K. from equation (4) is 2·992, and the manganese content of the metal bath is given by

$$\underline{Mn} = \frac{0{\cdot}16}{0{\cdot}34 \times 2{\cdot}992} = 0{\cdot}16\ \%.$$

To Determine the Manganous Oxide Content of a Slag in Equilibrium with a Metal of Known Manganese Content

Assume that $N_{FeO} = 0{\cdot}1$ and $N'_B/N_A = 2{\cdot}5$,* and that the temperature of the system is 1600° C. and the manganese content of the melt is 0·2%.

Now

$$N'_B + N_A = 0{\cdot}9 \text{ and } \frac{0{\cdot}9 - N_A}{N_A} = 2{\cdot}5$$

i.e.,

$$\frac{0{\cdot}9}{N_A} = 3{\cdot}5$$

$$\therefore N_A = 0{\cdot}257 \text{ and } N'_B = 0{\cdot}643.$$

From the FeO iso-activity diagram, a slag with $N_{FeO} = 0{\cdot}1$ and $N_A = 0{\cdot}257$ has an activity $a_{FeO} = 0{\cdot}475$, and since at 1600° C. (1873° K.) the manganese constant $K_{Mn} = 3{\cdot}304$,

$$a_{MnO} = 3{\cdot}304 \times 0{\cdot}475 \times 0{\cdot}2 = 0{\cdot}314.$$

Figure 4*b* shows that a slag with $N_{FeO} = 0{\cdot}1$ and $N_A = 0{\cdot}257$ has an activity $a_{MnO} = 0{\cdot}314$ at $N_{MnO} = 0{\cdot}138$ (*see* point *D*).

The desired slag composition is therefore:

$$N_{(CaO + MgO)} = 0{\cdot}505, \quad N_{MnO} = 0{\cdot}138,$$
$$N_{FeO} = 0{\cdot}1, \text{ and } N_{(SiO_2 + P_2O_5)} = 0{\cdot}257.$$

In a slag under the same conditions but with $N_{FeO} = 0{\cdot}08$, $N'_B + N_A = 0{\cdot}92$, and therefore $N_A = 0{\cdot}92/3{\cdot}5 = 0{\cdot}263$ and $N'_B = 0{\cdot}657$. The FeO iso-activity diagram shows that the activity of FeO is 0·39; thus,

$$a_{MnO} = 3{\cdot}304 \times 0{\cdot}39 \times 0{\cdot}2 = 0{\cdot}258.$$

Figure 4*a* shows that a slag with $N_{FeO} = 0{\cdot}05$ and $N_A = 0{\cdot}263$ has an activity $a_{MnO} = 0{\cdot}258$ at N_{MnO}

* $N'_B = N_{CaO} + N_{MgO} + N_{MnO}$, and $N_A = N_{SiO_2} + N_{P_2O_5}$.

$= 0{\cdot}090$ (*see* point *E*), and Fig. 4*b* shows that at $N_{FeO} = 0{\cdot}10$, $N_A = 0{\cdot}263$, and $a_{MnO} = 0{\cdot}258$, $N_{MnO} = 0{\cdot}112$ (*see* point *E'*). Interpolating linearly between these two values gives $N_{MnO} = 0{\cdot}103$ for $N_{FeO} = 0{\cdot}08$.

The desired slag composition is thus:

$$N_{(CaO + MgO)} = 0{\cdot}554, \qquad N_{MnO} = 0{\cdot}103,$$
$$N_{FeO} = 0{\cdot}080, \text{ and } N_{(SiO_2 + P_2O_5)} = 0{\cdot}263.$$

In a similar way, the FeO content of the slag could be determined if N_{MnO} were known.

References

1. E. T. TURKDOGAN and J. PEARSON: *J. Iron Steel Inst.*, 1953, vol. 173, pp. 217–223.
2. J. CHIPMAN: *Trans. Amer. Soc. Metals*, 1934, vol. 22, pp. 385–435.
3. J. CHIPMAN, J. B. GERO, and T. B. WINKLER: *Trans. Amer. Inst. Min. Met. Eng.*, 1950, vol. 188, pp. 341–345; *J. Met.*, 1950, vol. 2, Feb.
4. H. B. BELL, A. B. MURAD, and P. T. CARTER: *Trans. Amer. Inst. Min. Met. Eng.*, 1952, vol. 194, pp. 718–722; *J. Met.*, 1952, vol. 4, July.
5. F. KÖRBER and W. OELSEN: *Mitt. Kaiser-Wilhelm-Inst. Eisenforsch.*, 1932, vol. 14, pp. 181–204. *See also* F. KÖRBER: *Stahl u. Eisen*, 1932, vol. 52, pp. 133–144.
6. E. MAURER and W. BISCHOF: *Arch. Eisenhüttenwesen*, 1931–32, vol. 5, pp. 549–557.
7. T. B. WINKLER and J. CHIPMAN: *Trans. Amer. Inst. Min. Met. Eng.*, 1946, vol. 167, pp. 111–133; *Metals Technology*, 1946, vol. 13, Apr., Tech. Publ. No. 1987.
8. C. R. TAYLOR and J. CHIPMAN: *Trans. Amer. Inst. Min. Met. Eng.*, 1943, vol. 154, pp. 228–245; *Metals Technology*, 1942, vol. 9, Sept., Tech. Publ. No. 1499.
9. H. SCHENK: "Physical Chemistry of Steelmaking" (English Translation): 1945, London, British Iron and Steel Research Association.
10. F. HARDERS, H. GREWE, and W. OELSEN: *Stahl u. Eisen*, 1951, vol. 71, pp. 973–986.
11. H. SCHENK: *Arch. Eisenhüttenwesen*, 1930–31, vol. 4, pp. 319–332.
12. F. KÖRBER and W. OELSEN: *Mitt. Kaiser-Wilhelm-Inst. Eisenforsch.*, 1933, vol. 15, pp. 271–309.

Part III—PHOSPHORUS PENTOXIDE

SYNOPSIS

The equilibrium constant of the reaction involving the formation of phosphorus pentoxide from oxygen and phosphorus dissolved in iron has been calculated. This makes it possible to evaluate the activity coefficient of phosphorus pentoxide in slag when its concentration therein and those of oxygen and phosphorus in the metal are known.

Within the range studied, the activity coefficient is found to be a function of the slag composition of the type $\gamma_{P_2O_5} = \exp(-1.12 \times \Sigma A_i N_i + b)$, where A_i is a factor appropriate to a particular oxide constituent of the slag, its concentration being N_i mole fraction. The constant b is temperature-dependent. 822

MUCH attention has been given to dephosphorizing reactions in physico-chemical studies of steelmaking processes, but the interpretation of experimental results cannot be regarded as very satisfactory. Many attempts have been made to specify the precise nature of the dephosphorizing reaction, and although any particular scheme may explain satisfactorily the results on which it was based it frequently fails when applied to data from another source. This is probably due partly to the fact that arbitrary methods have been used for calculating the concentrations of reactants (' free ' lime, ferrous oxide, etc.) from the slag composition. Such methods are often adequate for evaluating equilibrium ratios over a restricted range of slag and metal compositions, but because they are, in fact, merely arbitrary and do not relate to actual concentrations or, more correctly, activities, they cannot be expected to hold when conditions are changed.

As pointed out elsewhere,[1, 2] it is not necessary to make any assumptions about the true nature of a slag in assessing the influence of composition on reaction equilibria. It is satisfactory merely to consider the reaction as taking place in the simplest possible way and then to ascertain how variations in slag composition alter the activities or activity coefficients of the reactants and products.

The object of this paper is to evaluate the activity coefficient of phosphorus pentoxide and to find a method of relating the variation of this coefficient to temperature and composition of basic steelmaking slags.

Paper CP/10/12 of the Chemistry Department of the British Iron and Steel Research Association, received 6th May, 1953.

THE PHOSPHORUS EQUILIBRIUM CONSTANT

The simplest model by which to indicate the dephosphorizing of iron by molten slags may be written

$$5\underline{O} + 2\underline{P} = P_2O_5 \text{ (liquid)} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The phosphorus pentoxide will dissolve in the slag, but this stage of the reaction should not be represented as forming tri- or tetracalcium phosphates, as such, because the extent to which such compounds exist in molten slags is unknown. The dissolution may be more correctly represented as

$$P_2O_5 \text{ (liquid)} + 3(O'') = 2(PO_4''') \ldots\ldots\ldots\ldots (2)$$

Equations (1) and (2) may be combined, as suggested by Herasymenko and Speight[3] and Flood and Grjotheim,[4] but no advantage accrues, since arbitrary methods must be employed to calculate the concentration of oxide ions in the slag, and an equilibrium constant cannot be derived without making assumptions as to the activities of oxide and phosphate ions. It is sufficient to consider that the phosphorus equilibrium is represented by equation (1) and that the activity of phosphorus pentoxide is changed when it is dissolved in the slag. It is to be expected that those slag constituents which tend to combine with phosphorus pentoxide will cause a marked lowering of its activity.

If the equilibrium constant of reaction (1) can be evaluated, it is possible to derive the activity and the activity coefficient of phosphorus pentoxide in any slag, provided that the activities of oxygen and

phosphorus in the metal in equilibrium therewith are known.

On the assumption that, at low concentrations, oxygen and phosphorus dissolved in iron obey Henry's law,

$$K_P = \frac{a_{P_2O_5}}{[O\%]^5[P\%]^2} \quad \ldots\ldots(3)$$

the standard states for oxygen and phosphorus being 1% by weight in iron. The value of K_P at any temperature may be derived by the following method:

The entropy of fusion of P_2O_5 has been estimated from a relationship published elswhere[5] to be about 17·5 cal./mole at 700° K., and thus

$$P_2O_5 \text{ (solid)} = P_2O_5 \text{ (liquid)}$$
$$\Delta G^\circ_T = +12{,}250 - 17{\cdot}5\,T \quad \ldots\ldots(4)$$

Now

$$P_2 \text{ (gas)} + 2\tfrac{1}{2}O_2 \text{ (gas)} = P_2O_5 \text{ (solid)}$$
$$\Delta G^\circ_T = -379{,}000 + 138{\cdot}5\,T \quad \ldots\ldots(5)[6]$$

$$2\,\underline{P}\ (1\%\text{ in iron}) = P_2 \text{ (gas)}$$
$$\Delta G^\circ_T = +58{,}500 + 9{\cdot}1\,T \quad \ldots\ldots(6)[7]$$

$$5\,\underline{O}\ (1\%\text{ in iron}) = 2\tfrac{1}{2}O_2 \text{ (gas)}$$
$$\Delta G^\circ_T = +139{,}650 + 2{\cdot}9\,T \quad \ldots\ldots(7)[8]$$

so that

$$2\,\underline{P}\ (1\%) + 5\,\underline{O}\ (1\%) = P_2O_5 \text{ (liquid)}$$
$$\Delta G^\circ_T = -168{,}600 + 133{\cdot}0\,T \quad \ldots\ldots(8)$$

It follows that

$$\log K_P = \frac{36{,}850}{T} - 29{\cdot}07 \quad \ldots\ldots(9)$$

THE ACTIVITY COEFFICIENT OF PHOSPHORUS PENTOXIDE IN BASIC SLAGS

Equation (3) may be rewritten

$$K_P = \frac{\gamma_{P_2O_5} N_{P_2O_5}}{[O\%]^5[P\%]^2} \quad \ldots\ldots(10)$$

where $\gamma_{P_2O_5}$ is the activity coefficient of phosphorus pentoxide dissolved in a slag at a concentration of $N_{P_2O_5}$ mole fraction, the slag being considered as made up from simple oxide constituents, CaO, MgO, FeO, MnO, SiO_2, P_2O_5, etc.

The activity coefficient of P_2O_5 in any slag can be calculated from equations (9) and (10) if the concentrations of oxygen and phosphorus in the metal are known. If the oxygen content is not known, or if the carbon content is greater than 0·05%, it should be calculated from the equation

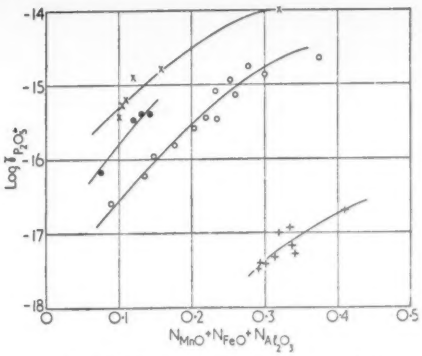
$$\underline{O}\% = a_{FeO} \times L_{FeO} \quad \ldots\ldots(11)$$

where a_{FeO} is the activity of ferrous oxide read from the FeO iso-activity diagram[1] and

$$\log L_{FeO} = -\frac{6320}{T} + 2{\cdot}734 \quad \ldots\ldots(12)[9]$$

It has been found that in slags containing appreciable quantities of alumina (up to 0·04 mole fraction) the correct activity of FeO can be read from the iso-activity diagram only if the Al_2O_3 is neglected and the remaining components are recalculated to a total of $N = 1$. As in parts I and II of this series, the ferric oxide content of the slag is neglected, all iron being calculated as ferrous oxide.

The results used in this paper are those obtained by Balajiva, Quarrell, and Vajragupta[10, 11, 12] and



	N_{CaO}/N_{SiO_2}	N_{MgO}	$N_{P_2O_5}$
×	2·8–3·2	0·09–0·12	0·04–0·06
●	3·6–3·8	,,	,,
○	4·0–4·5	,,	,,
+	8·0–10·0	,,	,,

Fig. 1—Effect of slag composition on the activity coefficient of phosphorus pentoxide, at 1585 ± 10° C.

Fischer and vom Ende,[13] from laboratory experiments, and by members of the staff of B.I.S.R.A. in collaboration with Messrs. John Summers and Sons Ltd., from analyses of metal and slag at tap from an open-hearth furnace. The data cover the following ranges:

Temperature:	1550–1660° C.
P	0·003–0·6 wt.-%
P_2O_5	0·01–0·2 mole fraction
SiO_2	0·01–0·2 ,, ,,
FeO	0·05–0·55 ,, ,,
CaO	0·40–0·78 ,, ,,
MgO	0·0–0·2 ,, ,,
MnO	0·0–0·1 ,, ,,
Al_2O_3	0·0–0·03 ,, ,,

The slags thus lie within the basic steelmaking range.

Fischer and vom Ende[13] showed that their results, obtained by equilibrating iron containing phosphorus with calcium phosphate slags in a lime crucible, obeyed approximately the relationship

$$K' = \frac{1}{[O\%]^5[P\%]^2} \quad \ldots\ldots(13)$$

and held this to confirm their assumption that in their slags the activities of lime and tricalcium phosphate were unity. Since the compositions of the slags were on neither the CaO nor the $Ca_3P_2O_8$ liquidus surfaces in the FeO–CaO–P_2O_5 ternary system, it follows that neither CaO nor $Ca_3P_2O_8$ was at unit activity. The validity of equation (13) would merely indicate that $(a_{Ca_3P_2O_8})/(a_{CaO})^3$ was constant under the conditions of their experiments; their constant K′ cannot be applied to other conditions.

Effect of Composition

The activity coefficients for a large number of slags were calculated with the aid of equations (9), (10), (11), and (12), and the results were found to vary. It was therefore sought to relate the activity coefficient to slag composition at a given temperature by classifying the slags into groups. As a first approximation, the slags were considered to belong to a CaO–MgO–(MnO + FeO + Al_2O_3)–SiO_2–P_2O_5 system. In Fig. 1, $\log\gamma_{P_2O_5}$ is plotted against the sum of the

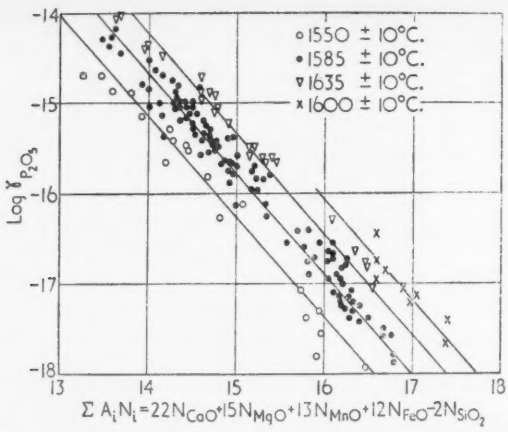


Fig. 2—Effect of slag composition and temperature on the activity coefficient of phosphorus pentoxide

mole fractions of MnO, FeO, and Al_2O_3 at fixed concentrations of MgO, P_2O_5, and CaO/SiO_2 ratios. Although in principle this is a satisfactory way of showing activity/composition relationships, the number of variables affecting the activity of P_2O_5 is so large that an excessive number of curves would be necessary to cover a sufficiently wide range of composition. Some degree of simplification is possible since Al_2O_3, being small, can be neglected, but even this leaves too many variables.

Under these circumstances it is of interest to recall that Flood and Grjotheim[4] have shown that the equilibrium ratio of a reaction not formally involving cations, but taking place in the presence thereof, can be written

$$\log K'' = \Sigma N_M \log K''_M \quad \ldots\ldots(14)$$

where K''_M is the equilibrium ratio of the reaction taking place in presence of the cation M only and N_M is the ionic fraction of that cation in a complex slag. It is to be expected that, for the reaction $2\underline{P} + 5\underline{O} = (P_2O_5)$, the equilibrium ratio K could also be written, for at least a restricted range of composition, as

$$\log K = \Sigma N_i \log K_i \quad \ldots\ldots(15)$$

where K_i is the equilibrium ratio for the reaction taking place in presence of a particular basic oxide and N_i is the mole fraction of that oxide in a complex slag.

The equilibrium constant for reaction (8) is given by

$$K_P = \frac{(a_{P_2O_5})}{[O\%]^5[P\%]^2} = \frac{\gamma_{P_2O_5} N_{P_2O_5}}{[O\%]^5[P\%]^2} = \gamma_{P_2O_5} K \quad \ldots(16)$$

It follows that

$$\log \gamma_{P_2O_5} = \log K_P - \log K,$$

so that, using equation (15),

$$\log \gamma_{P_2O_5} = -\Sigma N_i \log K_i + \log K_P \quad \ldots\ldots(17)$$

or

$$\log \gamma_{P_2O_5} = -\Sigma A_i N_i + b \quad \ldots\ldots(18)$$

This relationship probably will not hold over more than a limited range of compositions, and extrapolation to $\Sigma A_i N_i = 0$ should not be expected to give the value of $\log K_P$. There is no way of calculating the values of A_i, but it is possible to determine A_i by a method of trial and error, as did Flood and Grjotheim.[4] A series of whole numbers was sought for A_i which would give the best set of straight lines for an equation similar to (18). In Fig. 2, $\log \gamma_{P_2O_5}$ is plotted for four mean temperatures against $\Sigma A_i N_i$, where

$$\Sigma A_i N_i = 22N_{CaO} + 15N_{MgO} + 13N_{MnO} + 12N_{FeO} - 2N_{SiO_2} \quad \ldots\ldots(19)$$

The scatter of the points is not surprising, in view of the temperature range of $\pm 10°$ C. and the possibility that equilibrium had not been reached in every melt. The slope of the resulting lines is $-1{\cdot}12$, and equation (18) may thus be rewritten

$$\log \gamma_{P_2O_5} = -1{\cdot}12\,\Sigma A_i N_i + b \quad \ldots\ldots(20)$$

Effect of Temperature

Figure 2 indicates that the relationship between $\log \gamma_{P_2O_5}$ and $\Sigma A_i N_i$ is temperature-dependent. This is best illustrated in Fig. 3, in which the constant b of equation (20) is plotted against the reciprocal of the absolute temperature.

The best parallel lines through the points for the four temperatures in Fig. 2 may be represented by the equations:

At 1550°C., $\log \gamma_{P_2O_5} = -1{\cdot}12\,\Sigma A_i N_i + 0{\cdot}54$ ...(21)
„ 1585°C., $\log \gamma_{P_2O_5} = -1{\cdot}12\,\Sigma A_i N_i + 1{\cdot}03$ ...(22)
„ 1635°C., $\log \gamma_{P_2O_5} = -1{\cdot}12\,\Sigma A_i N_i + 1{\cdot}47$ ...(23)
„ 1660°C., $\log \gamma_{P_2O_5} = -1{\cdot}12\,\Sigma A_i N_i + 1{\cdot}85$ ...(24)

The temperature-dependence of the constant b, *i.e.*, 0·54, 1·03, etc., may be represented as

$$b = -\frac{42{,}000}{T} + 23{\cdot}58 \quad \ldots\ldots(25)$$

Combination of the above equations provides a general relationship for the effects of temperature and slag composition on the activity coefficient of phosphorus pentoxide:

$$\log \gamma_{P_2O_5} = -1{\cdot}12\,\Sigma A_i N_i - \frac{42{,}000}{T} + 23{\cdot}58 \quad \ldots(26)$$

With the aid of equation (26) it is possible to calculate, from slag analysis and temperature, the equilibrium phosphorus content in the metal under the slag.

DISCUSSION

The various mechanisms proposed for the dephosphorizing reaction are sufficiently well known to

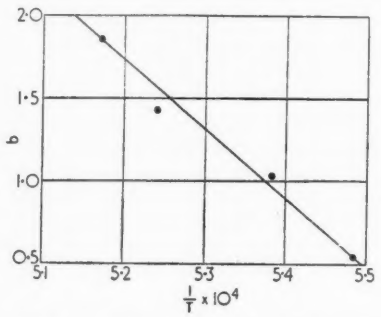


Fig. 3—Effect of temperature on the constant b

need no mention here. There has been, however, no simple proposal that relates equilibrium conditions to slag and metal compositions and temperature.

Phosphorus must be oxidized to enable it to pass from iron to slag, for there is no evidence that it can exist in steelmaking slags as phosphide. If the product of oxidation, *i.e.*, phosphorus pentoxide, formed an ideal solution in the slag, its activity would be equal to its mole fraction. Equation (8) indicates that reaction (1) cannot proceed to any useful extent under steelmaking conditions unless the activity of P_2O_5 is reduced very considerably, *e.g.*, to a value of the order of 10^{-15} to 10^{-20} mole fraction. This can be achieved if the slag contains available basic oxides that will allow the P_2O_5 to form phosphate ions. These phosphate ions will become more stable as the energy of interaction between P_2O_5 and the basic oxide increases, as is indicated by the free energy of formation of the corresponding molten or, to a rough approximation, solid phosphates. Bookey[14] has shown that tricalcium phosphate is more stable than trimagnesium phosphate, and it is thus to be expected that the activity of P_2O_5 in a molten slag will be lowered more by lime than by a corresponding amount of magnesia; manganous and ferrous oxides should be less effective than magnesia. This is reflected in the values of the factor A_i in equation (19). Sodium phosphate is even more stable than calcium phosphate,[15] and thus sodium oxide should be more effective than lime in lowering the activity of P_2O_5 in a basic slag. The work of Maddocks and Turkdogan[16] confirms this.

Since silica, dissolved in slag as SiO_4'''' ions, will tend to form silicates and so reduce the activity of the bases, at least in the composition range studied, it will raise the activity coefficient of P_2O_5. This is the implication of the last term in equation (19).

When considering the activities of ferrous and manganous oxides it was pointed out[1, 2] that their activity coefficients were not temperature-dependent so far as could be deduced from existing data. It might therefore be considered surprising that $\gamma_{P_2O_5}$ should be affected by temperature, as shown in Figs. 2 and 3. In fact, it is not possible to decide whether the temperature-dependence of $\gamma_{P_2O_5}$ is real or apparent. It will be seen from the derivation of equation (18) that the factors A_i are related to equilibrium ratios and should therefore change with temperature. They have been regarded as fixed, and thus any variations thereof with temperature are reflected in changes of $\gamma_{P_2O_5}$. This does not invalidate the usefulness of equation (25).

The results obtained by Winkler and Chipman[17] have not been included in the present calculations, because it was not possible to fit them into a common scheme. This difficulty has been mentioned previously.[3, 11] The discrepancy appears to be due to the fact that Winkler and Chipman employed neutral slags, and, as these have little connection with basic steelmaking practice, no thorough attempt has been made to correlate the results with those used here.

Because of lack of data, no comment can be made on the influence of fluoride on the activity of phosphorus pentoxide; it has been shown previously[1] that fluoride increases the activity of ferrous oxide.

CONCLUSIONS

Using existing data and an estimated heat of fusion the free-energy change for the following reaction has been evaluated:

$$2\,\underline{P}\,(1\%) + 5\,\underline{O}\,(1\%) = P_2O_5\ (\text{liquid})$$
$$\Delta G^\circ_T = -168{,}000 + 133{\cdot}0\ T\ \text{cal.}$$

It follows that

$$\log K_P = \frac{36{,}850}{T} - 29{\cdot}07,$$

where

$$K_P = \frac{(a_{P_2O_5})}{[P\%]^2[O\%]^5},$$

if phosphorus and oxygen, at the low concentrations at which they occur in steelmaking, obey Henry's law.

The activity coefficient of phosphorus pentoxide was found to be unaffected by the concentration of alumina in the slag, within the ranges of composition studied.

The activity coefficient of phosphorus pentoxide is raised by silica, but is lowered by basic oxides. The relationship may be represented by the equation

$$\log\gamma_{P_2O_5} = -1{\cdot}12\,\Sigma A_iN_i - \frac{42{,}000}{T} + 23{\cdot}58,$$

where

$$\gamma_{P_2O_5} = a_{P_2O_5}/N_{P_2O_5},$$
$$\Sigma A_iN_i = 22N_{CaO} + 15N_{MgO} + 13N_{MnO} + 12N_{FeO} - 2N_{SiO_2},$$

N = mole fraction of oxide constituent,

and T = absolute temperature.

References

1. E. T. Turkdogan and J. Pearson: *J. Iron Steel Inst.*, 1953, vol. 173, pp. 217–223.
2. E. T. Turkdogan and J. Pearson: *Ibid.*, 1953, vol. 175, pp. 393–398 (this issue).
3. P. Herasymenko and G. E. Speight: *Ibid.*, 1950, vol. 166, pp. 169–183.
4. H. Flood and K. Grjotheim: *Ibid.*, 1952, vol. 171, pp. 64–70.
5. E. T. Turkdogan and J. Pearson: *J. Appl. Chem.* (in the press).
6. F. D. Richardson and J. H. E. Jeffes: *J. Iron Steel Inst.*, 1948, vol. 160, pp. 261–270.
7. J. B. Bookey: *Ibid.*, 1952, vol. 172, pp. 61–66.
8. M. N. Dastur and J. Chipman: *Trans. Amer. Inst. Min. Met. Eng.*, 1949, vol. 185, pp. 441–445; *J. Met.*, 1949, vol. 1, Aug.
9. C. R. Taylor and J. Chipman: *Trans. Amer. Inst. Min. Met. Eng.*, 1943, vol. 154, pp. 228–247; *Metals Technology*, 1942, vol. 9, Sept., Tech. Publ. No. 1499.
10. K. Balajiva, A. G. Quarrell, and P. Vajragupta: *J. Iron Steel Inst.*, 1946, vol. 153, pp. 115–150.
11. K. Balajiva and P. Vajragupta: *Ibid.*, 1947, vol. 155, pp. 562–567.
12. P. Vajragupta: *Ibid.*, 1948, vol. 158, pp. 494–496.
13. W. A. Fischer and H. vom Ende: *Stahl u. Eisen*, 1952, vol. 72, pp. 1398–1408.
14. J. B. Bookey: *J. Iron Steel Inst.*, 1952, vol. 172, pp. 66–68.
15. F. D. Richardson, J. H. E. Jeffes, and G. Withers: *Ibid.*, 1950, vol. 166, pp. 213–235.
16. W. R. Maddocks and E. T. Turkdogan: *Ibid.*, 1949, vol. 162, pp. 249–264; 1952, vol. 171, pp. 128–136.
17. T. B. Winkler and J. Chipman: *Trans. Amer. Inst. Min. Met. Eng.*, 1946, vol. 167, pp. 111–133; *Metals Technology*, 1946, vol. 13, Apr., Tech. Publ. No. 1987.

The Tungsten/Molybdenum Thermocouple For Immersion Pyrometry

By J. P. Simons, C. G. Hamstead, and E. J. Burton

SYNOPSIS

Laboratory and works studies have been made of the possibility of using the tungsten/molybdenum thermocouple for measuring the temperature of liquid steel.

In Part I a laboratory investigation of the characteristics of the tungsten/molybdenum couple is described. An electric furnace using a graphite grid provided a quick and simple means of heating the thermocouples to 1900° C. for calibration against a disappearing-filament pyrometer. Calibration of the couples made from wires from five suppliers showed that consistent results were obtained from each batch. One supplier's wire gave the same calibration for three separate batches. Both annealed and unannealed couples gave the same calibration curve up to 1900° C. The couples were not contaminated by contact with alumina, but they were affected by graphite, although the effect was negligible in the time required to obtain readings with an immersion pyrometer.

In Part II a description is given of the tungsten/molybdenum immersion pyrometer for the measurement of liquid-steel temperature. A comparison in a steelworks of the readings of a tungsten/molybdenum pyrometer with those of a standard platinum/platinum–rhodium (13%) pyrometer have shown them to agree to $\pm$ 10° C. up to 1750° C. Measurements have been made up to 1850° C. after an oxygen blow in an electric-arc furnace, but its routine use awaits the manufacture of a robust sheath. Oxidation of the wires is adequately prevented for dip readings by a single refractory sheath.

Introduction

THE measurement of high temperatures in the steel industry demands a reliable base-metal thermocouple. Temperatures from 600° to 1100° C. may be measured either by the nickel–chromium/nickel–aluminium thermocouples (chromel/alumel and T_1 alloy/T_2 alloy types) or by the platinum/platinum–rhodium (13%) couple. The characteristics of the noble-metal couple have been thoroughly investigated during the last 40 years, and manufacturers can now supply wire which holds to the standard reference curve[1, 2] to $\pm$ 1° C. up to 1100° C. Nickel–chromium/nickel–aluminium couples consistently reproduce their standard reference curve[3] to within $\pm \frac{3}{4}$% and provide a cheaper alternative to Pt/Pt–Rh couples for many applications.

Above 1100°C. the Pt/Pt–Rh (13%) couple is the only recognized combination of metals available. A high-temperature couple of low cost but sufficiently accurate for industrial measurements, particularly for continuous measurements, would be very useful. Furthermore, oxygen is now being blown through liquid steel in the electric-arc furnace to reduce the refining time, and this raises the metal temperature well above the melting point of platinum.

The refractory materials that can be considered for a high-temperature thermocouple are few.

Schulze[4] reviewed the possibilities in 1939 and Burton and Weeks[5] have summarized recent developments. The most promising combinations include platinum–rhodium (20%)/platinum–rhodium (40%),[6] tungsten/graphite,[7–9] silicon-carbide/graphite,[10] iridium/iridium–rhodium (60%),[11] iridium/tungsten,[12,13] and tungsten/molybdenum.[14–18] The platinum alloy couple has the advantage of being accurately reproducible, but it has rather low sensitivity (about 3·5 μV./°C.) above 1000°C., and a comparatively low melting point (1895°C.). The tungsten/graphite and the silicon-carbide/graphite thermocouples are cheap, but they are unwieldy compared with wire thermocouples and have characteristics that are not sufficiently reproducible. The Ir/Ir–Rh (60%) and the Ir/W thermocouples are reliable, but they are unsuitable for industrial applications because of the

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Mr. Simons and Mr. Burton are in the Physics Department of B.I.S.R.A., and Mr. Hamstead is with Edgar Allen and Co., Ltd.

high cost and brittleness of iridium. The last combination of metals, W/Mo, is cheap and has an adequate sensitivity (6·5 μV./°C. above 1250°C.) and a high melting point (molybdenum melts at 2625°C.). However, the published data about its reproducibility are rather contradictory, and the couple has rarely been used for industrial measurements. Therefore it was decided to make an independent examination.

Part I—The Characteristics of the Tungsten/Molybdenum Thermocouple

By J. P. Simons

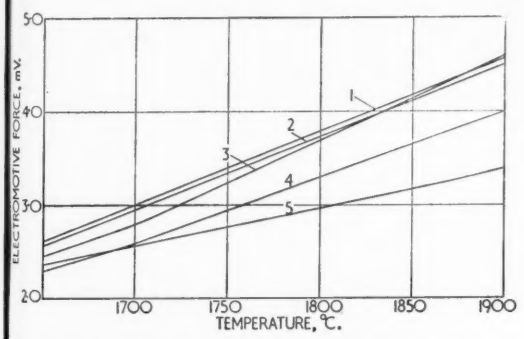
REVIEW OF PREVIOUS WORK

THERE are considerable differences between the published calibration results for the W/Mo thermocouple. A comparison of the calibration curves is given in Fig. 1. Most investigators agree that their calibrations differ from one batch of wire to another, and so the wide variability of results is not surprising. However, Greenaway, Johnstone, and McQuillan[15] stated that results on a second batch of materials indicated that there was no significant difference between its calibration and that of the earlier batch. Morgan and Danforth[16] claimed good agreement between their results and those of Osann and Schröder.[14] Potter and Grant,[17] on the other hand, found a difference of 100° C. at 1600° C. between two batches of wire. No satisfactory explanation of this variability can be found in the literature. It is probably due to chemical impurities and differences in manufacturing technique.

There is general agreement among the investigators that the calibration for any given batch of wire is reproducible. The batch effect is therefore not a serious disadvantage, because a quantity can be bought large enough to last a long time and this will only need one calibration.

Another characteristic that has been widely observed is a change in calibration due to ageing during prolonged use of unannealed thermocouples. It is usually recommended that these thermocouples should be annealed, although the process makes the wires brittle. Fetters and Chipman[19] found that ageing did not occur if the thermocouples were annealed near the melting point of molybdenum, thus completely recrystallizing the wire. Greenaway, Johnstone, and McQuillan[15] compared the calibrations of annealed and unannealed wire and found very little difference up to 2100° C.

Most investigators, aware of the susceptibility of tungsten and molybdenum to oxidation at high temperatures, have been careful to calibrate and use their thermocouples in an inert atmosphere. Osann and Schröder,[14] however, found it possible to use their thermocouples for 2 hr. without a significant loss of accuracy in an ordinary ambient atmosphere maintained in a protection sheath of small bore.



1. McQuillan[15]
2. Morgan and Danforth[16]
3. Osann and Schröder[14]
4. Potter and Grant[17]
5. Troy and Steven[18]

Fig. 1—Comparison of five published curves for the W/Mo thermocouple. These curves have been estimated from those published, and should be considered as only approximate.

LABORATORY INVESTIGATION

Preparing the Thermocouples

Thermocouples 2 ft. long, composed of wire 0·3 mm. thick, were used in the experiments. Thicker wire is too rigid for easy manipulation and thinner wire is too fragile when heated. The hot junctions were made without difficulty by winding the molybdenum wire tightly round the tungsten for four or five turns, as suggested by Potter and Grant.[17] The twisted junction was then welded in a tungsten arc, using a welding unit similar to that described by Hickson;[20] the unit is shown in Fig. 2. About 100 V., D.C., is applied between the couple junction and the tungsten electrode, and the weld may be made in any inert atmosphere. The couple wires are held apart up to the junction by alumina twin-bore insulators.

Calibration Technique

The furnace shown in Fig. 3 was used to calibrate the thermocouples. This is based on a design by Burton and Simons of a prototype calibration furnace for standard immersion pyrometers. It consists essentially of a graphite grid cut from a plate, with the centre bar drilled to form a $5\frac{3}{4}$-in. long tube of 0·5-in. bore. The grid, mounted in a steel box packed with carbon powder as insulating material, is heated by an electric current of about 400 amp. at 9·0 V., which brings the tube to 1850° C. in about 10 min.; the tube is maintained at this temperature by a current of about 300 amp. at 6·5 V. The current leads are attached to the grid by water-cooled brass electrodes. The furnace can be steadied quickly and easily at any desired temperature up to 1900° C.

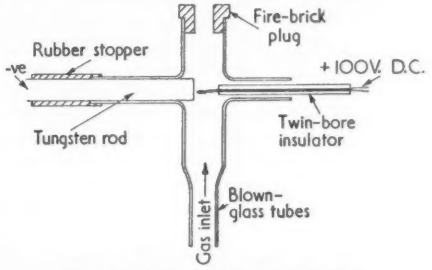


Fig. 2—Arc-welding apparatus

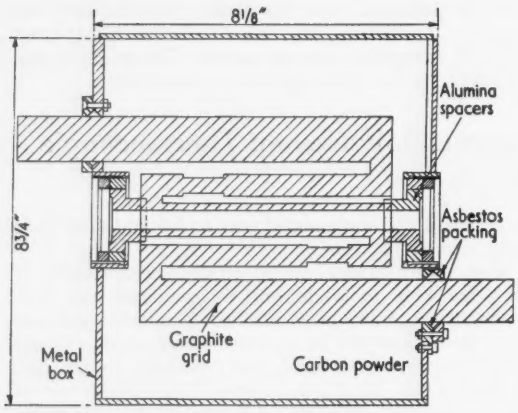


Fig. 3—Calibration furnace for W/Mo thermocouples

When a thermocouple was to be calibrated its hot junction was pushed to the closed end of an alumina sheath situated in the furnace tube. An optical pyrometer measured the temperature of the sheath tip, and this measurement was compared with the e.m.f. of the thermocouple at various temperatures over the required range. The cold junction was allowed to remain at room temperature, which was measured. The following preliminary experiment ensured that the optical pyrometer measured the true hot-junction temperature of the thermocouple. The sheath containing a Pt/Pt–Rh (13%) thermocouple was moved along the tube until the temperature measured by the thermocouple was equal to that measured by the optical pyrometer. The sheath was then fixed in this position for the W/Mo calibrations.

Annealing

Annealing the couple makes it brittle and difficult to handle, and so a technique was devised which made handling easy in the laboratory and could be used, if required, in industrial measurements (*see* Fig. 4). A heavy current is passed through the last 3 in. of the couple only, and its temperature is raised to about 2000° C. (*i.e.*, a brightness temperature of about 1800° C. as measured by an optical pyrometer). The brass-screw electrodes allow this to be done without disturbing the shape of the wire, so that the alumina insulators can be carefully pushed back over the annealed length. The annealing process can be carried out in any inert atmosphere. Unannealed wire was also used in the experiments, although, of course, the calibration process itself anneals each thermocouple in the region of the hot junction.

Atmosphere

Nitrogen is reported to affect the properties of these wires. However, no significant difference was found on comparing the results of a thermocouple calibrated in nitrogen with those of a similar thermocouple calibrated in argon. Thus, at least for an initial calibration, nitrogen can be considered to act as an inert atmosphere. For most of these experiments a small positive pressure of oxygen-free nitrogen was maintained in the alumina sheath.

Calibration and Cold-Junction Correction

A thermocouple from supplier *A* was calibrated between 100° and 1700° C. against a Pt/Pt–Rh (13%) thermocouple when the hot junctions of both were at the end of the same alumina sheath in the furnace. The parabolic curve obtained is shown in Fig. 5. The output from the couple is zero again at 1220° C. For cold-junction corrections, the thermocouple was calibrated between 0° and 50° C. against a chromel/alumel thermocouple in a water bath. This curve is also given in Fig. 5. Because of the inversion of the e.m.f. at 1220° C., above this temperature cold-junction corrections must be added and not subtracted from the standard curve referred to the ice point.

High-Temperature Experiments

Reels of tungsten and molybdenum wire were obtained from five suppliers (*A*, *B*, *C*, *D*, and *E*). Thermocouples annealed in nitrogen and made from wire from sources *A* and *E* were calibrated in nitrogen and the results were compared with those from unannealed couples. There was no significant difference between the two sets of curves and so unannealed wire was used for most of the experiments. Calibration curves were then obtained for all five suppliers' wire and are shown in Fig. 6*a*. Every curve was reproduced several times using different thermocouples.

The batch effect previously discussed was then investigated for wire from suppliers *C* and *A*. The calibration curve for thermocouples constructed from the second batch of wire from supplier *C* differed by about 55° at about 1850° C. from the curve obtained for the first batch. The two curves are compared in Fig. 6*b*.

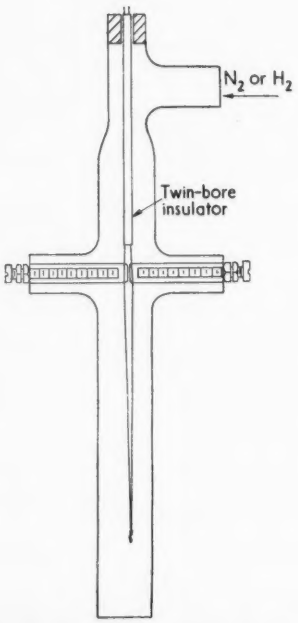


Fig. 4—Tungsten/molybdenum annealing unit

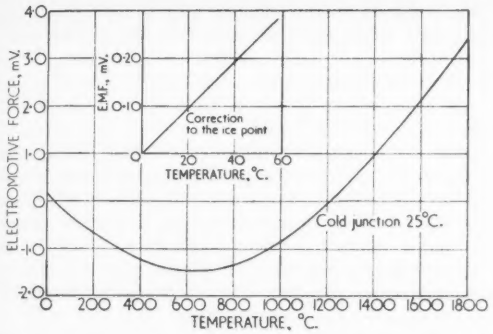


Fig. 5—Calibration curve of the W/Mo couple (wire from supplier *A*)

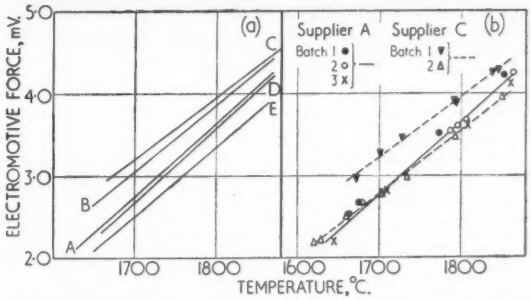


Fig. 6—Temperature/e.m.f. curves for W/Mo couples made from (*a*) wire from five suppliers, and (*b*) different wire from two suppliers (*A* and *C*)

Two more batches of wire were acquired at intervals of a few months from supplier *A*. They both reproduced the curve obtained for the first batch within ± 10° C., as shown in Fig. 6*b*.

To test any ageing on the unannealed wire from supplier *A*, the hot junction of an uncalibrated thermocouple was pushed quickly to the sheath tip. Four or five optical pyrometer and thermocouple comparison measurements were then made every minute for about ½ hr. The averages of the readings observed during each minute were then compared with the calibration curve. There was no significant deviation during the whole time of heating. Similar results were obtained on the wire from source *E*. In a variation of this experiment the observations were interrupted for the thermocouple to be withdrawn and allowed to cool. It was then re-inserted for further observations. This procedure had no apparent effect on the thermocouple.

Contamination by Alumina and Graphite

Alumina powder packed tightly around a thermocouple offered one possible method of preventing oxidation of the wires during steelworks trials. A thermocouple made from wire supplied by *C* was therefore embedded in alumina powder and its e.m.f./temperature curve was determined. There was no difference between this curve and one obtained in an atmosphere of nitrogen.

Thermocouples made of wire from suppliers *A* and *E* were tested for their resistance to contamination by graphite, since this was possibly a suitable sheath material for measurements in liquid steel. The alumina sheath in the calibration furnace was replaced by a graphite sheath. An unwelded thermocouple was pushed along this sheath until the two wires projected through two small holes drilled axially through the closed end. The hot junction was then welded so that it was situated outside, but in contact with, the closed end of the sheath. The thermocouple was then calibrated as described on p. 404. Tests were also made by pushing the graphite sheath containing the thermocouple into the furnace when the latter was at a steady temperature of about 1850° C.

Although for both wires the freshly inserted couple gave an e.m.f. which lay on the standard calibration curve, the e.m.f. slowly increased. The difference was small after 5 min.—ample time for a dip reading—but it corresponded to a difference in apparent temperature of about + 25° C. at 1700° C. after 15 min. One couple was unaffected by the graphite, and it seems possible that a careful investigation of the cause of contamination will eventually enable the effect to be eliminated.

Part II—The Tungsten/Molybdenum Immersion Pyrometer

By C. G. Hamstead and E. J. Burton

THE laboratory experiments showed that the couple's characteristics were sufficiently reproducible for accurate temperature measurements, but there had been no experience of its use for industrial measurements, except for the early experiments by Osann and Schröder.[14] This was particularly needed to examine the effect of the two disadvantages of the couple, *i.e.*, that the wires are easily oxidized and become brittle after heating. Also, a couple was now available to measure temperatures above the melting point of platinum (1769° C.).

CONSTRUCTION OF THE IMMERSION PYROMETER

Tungsten and molybdenum wires are much stiffer than platinum or platinum–rhodium (13%) ones, but by using wire of 0·3 mm. dia. it was possible to use them to replace simply the wire in a standard hand immersion pyrometer. The wire was threaded easily through the aluminous-porcelain insulators, and at the hot junction twin-bore alumina insulators were used. About ½–¾ in. of wire was exposed before the hot junction; this length could not be extended without the danger of the wires fracturing if the protection sheaths warped during immersion. The junction was welded as described on p. 403.

The parts for the welding were assembled into a box to make a unit that was easily portable and could be used either in the pyrometry cabin or in the melting shop, provided that a source of 100 V., D.C., was available.

TEMPERATURE MEASUREMENT BELOW 1750° C.

Wire from two suppliers, *A* and *E*, has been used. The couples were calibrated as described on p. 404, and the calibration curves are shown in Fig. 6. A check of the calibration of both wires was made about six months after the original results and no change was found. During this time the wire from supplier *E* had been used in the works and the check was made on the wire finally remaining on the pyrometer spools.

A comparison between the temperatures measured by the W/Mo immersion pyrometer and the standard Pt/Pt–Rh (13%) immersion pyrometer was made to give a measure of the reliability of the new pyrometer. The readings were taken by dipping the W/Mo pyrometer in the liquid steel of either a 2-ton electric-arc furnace or a H.F. furnace immediately after the standard instrument. The readings of the Pt/Pt–Rh pyrometer were taken directly from the indicator of of the amplifier installation. The e.m.f.'s of the W/Mo couple were measured on a portable potentiometer.

The temperatures indicated by the two couples generally agreed to within 10° C. The W/Mo couple often read higher because the temperature of the steel was still rising. The readings are summarized in Table I. The wires did not oxidize appreciably during one immersion, and so it was not necessary to use alumina powder as a protection. The brittleness of the tungsten and molybdenum wires after heating prevented a second reading being taken. Therefore, 6 in. of the wire were pulled through the pyrometer and a new junction was welded; this took about 5 min.

The time to reach a steady reading is longer with the W/Mo pyrometer than with the Pt/Pt–Rh couple. Using a standard silica sheath 6 in. long, 9 mm. outer dia., and 1·5 mm. wall thickness, the Pt/Pt–Rh (13%) couple takes on an average 20 sec., whereas the W/Mo couple takes about 35 sec. This difference is mainly due to the proximity of the twin-bore alumina insulators to the W/Mo junction.

Some commercial amplifiers used with immersion-pyrometry equipment are liable to give trouble if there are appreciable leakage currents to earth at the input. Particular care must therefore be taken when using a conducting sheath such as graphite, because the couple will be earthed if it touches the sheath on immersion into the steel. The effect can be eliminated by a change in the circuit design.

Several measurements were made using alumina protection sheaths covered with alumina cement. This was to gain experience in using alumina for steel immersions without cracking the sheath from thermal shock. Alumina is one of the few materials that will withstand temperatures of 1850° C., and it was therefore used in the very-high-temperature experiments described in the next section.

TEMPERATURE MEASUREMENT ABOVE 1750° C.

Temperatures of at least 1850° C. are obtained in the electric-arc furnace after oxygen has been blown through the steel. Attempts were made to measure these temperatures with the W/Mo immersion pyrometer.

After the pyrometer had been asembled, a coating of Sairset cement was applied from the base of the sheath to about 1 ft. along the horizontal part of the pyrometer. The pyrometer was not used until the cement had dried thoroughly.

Table I

COMPARISON OF TEMPERATURES MEASURED BY THE Pt/Pt–Rh (13%) PYROMETER WITH THE W/Mo PYROMETER READINGS

Type of Furnace	Temp. Given by Pt/Pt–Rh (13%), °C.	Tungsten/Molybdenum		Time of Immersion of Pt/Pt–Rh (13%), sec.	Time of Immersion of W/Mo, sec.	Supplier of W/Mo Wire	Remarks on W/Mo Measurement
		E.m.f., mV.	Temp., °C.				
Electric arc	1600	1·72	1585	...	70	E	Recrystallized - alumina sheath preheated for 1½ min. above steel bath
	1620	2·18	1645	...	90	E	Alumina sheath, covered with alumina cement, preheated for 1 min.
	1590	1·80	1595	...	60	E	Alumina sheath, covered with alumina cement, preheated for 1¾ min.
	1610	1·91	1610	...	60	E	Alumina sheath, covered with alumina cement, preheated for 1¼ min.
H.F.	1750	2·60	1700	...	180	E	Alumina sheath, covered with alumina cement
	1650	2·26	1660	...	180	E	" " " "
H.F.	1670	2·72	1680	20	55	A	Standard silica sheath
	1670	2·71	1680	...	32	A	" " "
	1750	3·33	1755	15	21	A	" " "
	1680	2·70	1680	22	30	A	" " "
	1710	3·03	1720	...	21	A	" " "
	1700	3·02	1720	...	25	A	" " "
	1670	2·68	1680	25	27	A	" " "

Several types of sheath and protective coating were tried as substitutes for the silica sheaths. Readings were obtained with alumina sheaths and with thin graphite sheaths covered with alumina cement, but neither offered the same simplicity and reliability as the silica sheath in the lower temperature range. The alumina sheaths crack on immersion, although this is reduced by pre-heating over the bath, and the graphite sheath is rapidly dissolved by the decarburized steel once it penetrates a crack in the protective coating. Also, the protective coating lengthens the response time to 2–4 min., which, at these temperatures, greatly endangers the life of the pyrometer itself. This problem is difficult to solve because not only is the temperature close to the melting point of the refractories, but there is also a vigorous swirl in the bath and the slag attacks the refractory.

Zircon sheaths coated with cement have been tried,[21] but they are mechanically weaker than alumina. A silicon-carbide sheath with a thin coating of Zirconia cement has also been tried. This withstood the thermal shock, but it was dissolved away. A temperature of 1840° C. was measured before the sheath failed, although the reading was still increasing.

CONCLUSIONS

From Laboratory Investigations

(1) The W/Mo couple is reliable, three separate batches of wire from one supplier having given the same calibration curve to ± 10° C. at 1850° C.

(2) The couple does not need annealing when used up to 1900° C.

(3) A graphite-grid furnace provides a quick method of heating the couples for calibration.

From Steelworks Trials

(1) The W/Mo immersion pyrometer is a cheaper alternative to the Pt/Pt–Rh (13%) couple for use when rather less accurate measurements are required.

(2) Temperatures of liquid steel above the melting point of platinum can be measured.

(3) Oxidation of the wires does not prevent dip readings, when the wire is protected with a single refractory sheath.

(4) The time response of the W/Mo immersion couple is nearly half as much again as that of the Pt/Pt–Rh couple.

(5) The hot junction of the couple is too brittle for more than one immersion reading. This will not make continuous temperature measurements impossible, provided that a permanent installation is designed where the couple need not be moved.

Acknowledgments

Thanks are due to Edgar Allen and Co., Ltd., for allowing the authors to work on this project and for providing the facilities to make the measurements. Mr. K. P. Perry gave valuable assistance in calibrating the couples and Mr. P. W. Willows constructed the welding unit.

References

1. C. R. Barber: *Proc. Phys. Soc.*, 1950, vol. 63, ser. B, pp. 492–503.
2. British Standard Specification 1826: 1952, London, British Standards Institution.
3. British Standard Specification 1827: 1952, London, British Standards Institution.
4. A. Schulze: *J. Inst. Fuel*, 1939, vol. 12, pp. s41–s48.
5. E. J. Burton and D. J. Weeks: *Ibid.* (in the press).
6. T. Land: Private communication.
7. H. L. Watson and H. Abrahams: *Transactions of the American Electrochemical Society*, 1928, vol. 54, pp. 19–31.
8. F. Holtby: *Trans. Amer. Found. Soc.*, 1939, vol. 47, pp. 854–872.
9. L. Losana: *Met. Ital.*, 1940, vol. 32, pp. 239–241.
10. G. R. Fitterer: "Temperature: Its Measurement and Control in Science and Industry," pp. 946–957: 1941, New York, Reinhold Publishing Corporation.
11. O. Feussner: *Elektrotechnische Zeitschrift*, 1933, vol. 54, pp. 155–156.
12. W. C. Troy and G. Steven: *Trans. Amer. Soc. Metals*, 1950, vol. 42, pp. 1131–1149.
13. *Ibid.*, 1950, vol. 42, pp. 1150–1160.
14. B. Osann and E. Schröder: *Arch. Eisenhüttenwesen*, 1933, vol. 7, pp. 89–94.
15. H. T. Greenaway, S. T. M. Johnstone, and M. K. McQuillan: *J. Inst. Metals*, 1951, vol. 80, pp. 109–114.
16. F. H. Morgan and W. E. Danforth: *J. Appl. Phys.*, 1950, vol. 21, pp. 112–113.
17. R. D. Potter and N. J. Grant: *Iron Age*, 1949, vol. 163, Mar. 31, pp. 65–69.
18. S. Morugina: *Zeitschrift für technische Physik*, 1926, vol. 7, pp. 486–489.
19. K. L. Fetters: Sc.D. Thesis, 1940, Department of Metallurgy, Massachusetts Institute of Technology.
20. V. M. Hickson: *J. Sci. Instruments*, 1940, vol. 17, pp. 182–186.
21. T. Land: Private communication.

Correspondence on the Paper—

SIGMA-PHASE EMBRITTLEMENT IN 25Cr–20Ni HEAT-RESISTING STEELS*

By J. I. Morley and H. W. Kirkby

Mr. **E. J. Dulis** (United States Steel Corporation) wrote: This paper presents some interesting observations that will undoubtedly lead to a better understanding of this commonly used heat-resisting steel. The results of our own study[1, 2, 3] of the effect of prior treatment on σ formation in 25/20 Cr–Ni steel and of the influence of σ formation on mechanical properties of this steel at both room temperature and elevated temperatures largely substantiate the data reported by Morley and Kirkby.

They found, as we did, that the initial annealing temperature can markedly influence the rate of σ formation. However, the statement that ". . . . coarse grain size,

J. Iron Steel Inst., 1952, vol. 172, pp. 129–142.

Table A

EFFECT OF PRIOR HEAT-TREATMENT AND SIGMA FORMATION ON ROOM-TEMPERATURE MECHANICAL PROPERTIES

Treatment	Hardness, D.P.N.	A.S.T.M. Grain Size	Yield Strength (0·2% Offset), lb./sq. in.	Tensile Strength, lb./sq. in.	Elongation, %	Reduction in Area, %
Annealed 926° C.; unexposed*	198	7	49,900 51,600	102,400 104,600	40·0 36·0	57·0 54·0
Annealed 926° C.; exposed†	265	7	57,600 58,000	116,100 117,700	11·0	11·6
Annealed 1093° C.; unexposed*	142	1	36,000 36,300	85,000 84,500	58·0 59·0	80·0
Annealed 1093° C.; exposed†	279	1	56,800 56,600	116,500 118,500	5·0	5·3 5·6
Annealed 1260° C.; unexposed*	130	0	30,600 31,400	77,500	61·0 68·0	80·0 82·0
Annealed 1260° C.; exposed†	287	0	58,000 54,400	92,500‡ 76,500‡	1·0 0·5	0·6 1·6

* W.Q. from annealing temperature † 7500 hr. at 704° C. ‡ Disparity attributed to brittleness, which causes scatter

on the other hand, appears to have little influence on the rate of precipitation in steels that precipitate 20% or more of σ . . . " is not in agreement with our data. We found that the effect of high-temperature annealing, with its accompanying coarse grains, persisted at an exposure temperature of 704° C. in a steel that formed 30% of σ.[1] In addition, we found that the cooling rate from 1150° or 1260° C. markedly influenced the rate of σ formation ; the slower cooling rates (air and furnace cooling), which resulted in grain-boundary carbides, gave retarded rates of σ precipitation. As we expected, the final grain sizes were not influenced by cooling rate. The authors' opinion that the slower rates of σ formation in steels initially annealed at high temperatures may be due to the solution of chromium carbides that precipitate before the formation of σ seems questionable in view of our findings in the cooling-rate studies.

The accelerating effect of cold work on σ formation (Table VI of the paper) is somewhat less marked than the effect we reported[2] ; however, the authors used tensile deformation, whereas we used cold-drawing (drawing through dies). After heating samples for 100 hr. at 704° C., we found 15% of σ in the sample that had been cold-drawn 36%, compared with 2% of σ in the sample that had not been cold-drawn. Furthermore, the σ particles in the cold-drawn specimens were smaller and were more numerous than in the undrawn specimens, an effect that persisted even after a 5000-hr. exposure. This indicates that the effect of cold work is to induce nuclei for subsequent σ growth.

In our investigation[3] to determine the effect of σ on the strength and ductility of 25/20 Cr–Ni steel, we exposed specimens, after various solution treatments, to a temperature of 704° C. for 7500 hr. This period of time was considered to be long enough to form in each specimen the equilibrium amount of σ, *i.e.*, about 30%. The room-temperature hardness and tensile results given in Table *A* show the effect of the greater amount of σ (30%) that formed at 704° C. compared with the findings of Morley and Kirkby for steels exposed at 800° C. The distribution of σ resulting from the different heat-treatments must also have influenced the mechanical properties. Charpy keyhole-notch impact tests showed all the exposed samples to have a low notch toughness (3–4 ft. lb.), even when the testing temperature was raised to 260° C.

AUTHORS' REPLY

Mr. **J. I. Morley** and Mr. **H. W. Kirkby** (Brown-Firth Research Laboratory) wrote in reply : We thank Mr. Dulis for his remarks and we would confirm that the results of our investigations and those of Mr. Dulis and his colleagues largely agree.

We cannot offer at this stage any explanation other than that given in our paper for the difference in the behaviour of steel *C* compared with that of steels *A* and *B*. There are points of difference which may explain the different experiences :

(*a*) Steel *C* was exposed at 800° C., whereas Mr. Dulis was concerned with 704° C.

(*b*) All our test specimens were initially air-cooled in fairly small sizes. Therefore, if our steel *C* is sensitive to the rate of cooling in terms of rate of σ formation, we would not have been in a position to observe it

(*c*) The higher silicon content of steel *C*.

We do not attribute the slower formation of σ phase in the higher-temperature-annealed material solely to the action of the carbides. We observed that carbides were present at the grain boundaries before σ phase, and when the latter appeared the boundary carbides disappeared. On p. 133 of our paper we discuss this point and suggest that there are probably other factors influencing the phenomenon in question.

On the question of strength and ductility, we consider that Mr. Dulis's results (Table *A*) are largely in agreement with our findings, bearing in mind the greater amount of σ phase present and the difference in exposure temperatures.

REFERENCES

1. G. V. Smith, E. J. Dulis, and H. S. Link : *Welding J.*, 1951, vol. 30, pp. 385s–396s.
2. E. J. Dulis and G. V. Smith : *Metal Progress*, 1952, vol. 62, pp. 86–87.
3. G. V. Smith and E. J. Dulis : *Amer. Soc. Test. Mat.*, 1953, *Spec. Tech. Publ. No.* 128, pp. 225–235.

IRON AND STEELWORKS ENGINEERING

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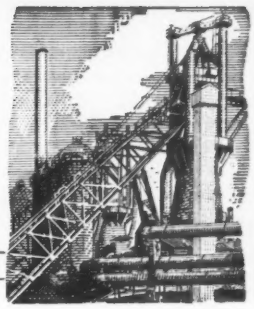

Belt-Charged Blast-Furnaces of S.A. John Cockerill, Belgium

By

G. Hookham, M.I.Mech.E., M.Inst.F.

SYNOPSIS

After briefly reviewing the reasons for adopting a belt system, the installation is described, and it is shown how the many new problems encountered in design and practical operation were solved.

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DEVELOPMENT

THREE modern larger furnaces were planned to replace a line of four old ones, one of them to be installed immediately and the other two at later stages. The old furnaces were charged by a telpher bucket system, the main haul of which was powered, but hand tramming was used at the loading stations and at the furnace tops. The buckets were fairly small, and much labour, which was becoming scarce, was required.

The bunkers of the old furnaces were nearly in line with the furnaces, but some distance away on a high mound of slag and refuse. The furnaces themselves were flanked on one side by a continuous line of stoves, and on the other, and quite close, by a Bessemer steel-plant. As there was no room for an orthodox system of inclined skip hoists and bins, it was decided, after a full investigation, to build a new set of bins beside the old ones on the mound, but exactly in line with the furnaces, and to transport the charges by belt conveyors. The telpher buckets had discharged direct on to the old large bells, but it was now planned to discharge from the belts into modern revolving hoppers. The extra height required for this, in addition to the increased height of the new furnaces, placed the belts above the existing telpher system, which is still charging two of the old furnaces.

The first stage—building the first furnace and its charging equipment—has now been completed, and the furnace, of 18 ft. hearth dia., has been operating for three years, producing more than 400 tons of basic iron per day from a burden mainly of lean Minette ores. Brief descriptions of the plant have been given.*

A cross-section of the new No. 1 furnace is shown in Fig. 1 ; Fig. 2 shows the top of the furnace, and also the central gas offtakes of the two old furnaces that are still in operation and the structural work carrying the telpher systems. The bulge in the conveyor gantry is in line with the future No. 2 furnace, and the nearer gas offtake, that of the present No. 4 furnace, is in line with the future No. 3 furnace.

In addition to the four old telpher-charged furnaces, there was another group of three furnaces almost beside the new bin system. They had their own bunkers and were charged by single skips, which, in turn, were filled by hand-charged telpher buckets, the skips discharging into 'Brown' tops. Two of them, Nos. 5 and 7, have been enlarged and reconditioned, a modern top has been fitted to No. 5 furnace, and belt charging from the new bin system has been installed. This went into operation shortly after the new No. 1 furnace. A new top is now being fitted to No. 7 furnace and the belt system extended to it also. No alterations are to be made to No. 6 furnace.

A plan of the plant is shown in Fig. 3, which also shows the ore preparation and handling plant and the coke handling system. Ore is received in wagons which are unloaded by a tippler into the crushing-plant receiving hopper. After crushing to 2½-in. size, the ore is conveyed to the new bin system either direct or *via* a stockyard. Fines are extracted and sintered. Provision is made for the later installation of a bedding plant. Coke is brought from ovens in the works by an aerial rope-way to the coke station, with final discharge into the new bins by belt.

BELT-CHARGING SYSTEM

Although the belt system for charging the second group of furnaces had its own special problems, its principle is the same as for the first group, *i.e.*, the line of three, and this description is therefore confined to the equipment serving the first group.

* L. Halbrecq, *Blast Furn. Steel Plant*, 1953, vol. 41, pp. 743–750, and J. Miles and T. Thomson, *Iron Coal Trades Rev.*, 1952, vol. 164, pp. 1073–1078.

Manuscript received 28th September, 1953.

Mr. Hookham is a Director and Chief Development Engineer of John Miles and Partners (London), Ltd.

To ensure continuous operation, the charging system for these has been designed for eventual duplication, when the old bunkers and the lower end of the existing telpher, which are in the way of the second line, can be removed. The two systems will be identical and entirely independent of each other, with duplicate belts, feeders, scale cars, and control systems. Each will be able to maintain, with a considerable margin, the full charging rate for three furnaces.

A diagrammatic arrangement of the charging system is shown in Fig. 4. The coke hoppers (*C*1–*C*4) are filled automatically to pre-set quantities, and the ore feeder hoppers (*O*1–*O*3) are filled by means of the double-compartment scale car which picks up its load from the bins above. The batches of coke and ore so collected are discharged at suitable intervals on to the continuously running belt system (*B*1–*B*4). Belts *B*3 and *B*4 reverse, as required, to discharge the load into the furnace for which it is intended.

Three ore loads are sent up in succession, one for each furnace in turn, and similarly with the coke loads. A coke load represents a layer about 12 in. thick in the throat of the furnace. The ore load, slightly less in volume, is the amount from both compartments of the scale car.

The small bells are lowered for every load, and the large bells when two loads from the small bells have

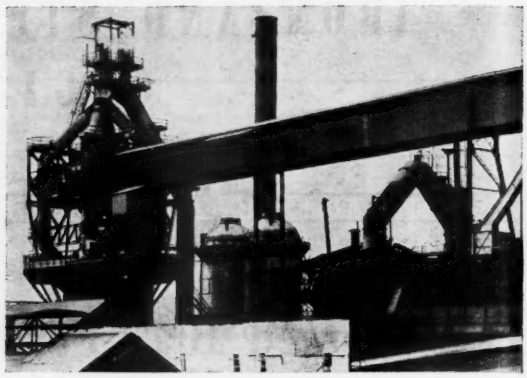


Fig. 2—New No. 1 blast-furnace

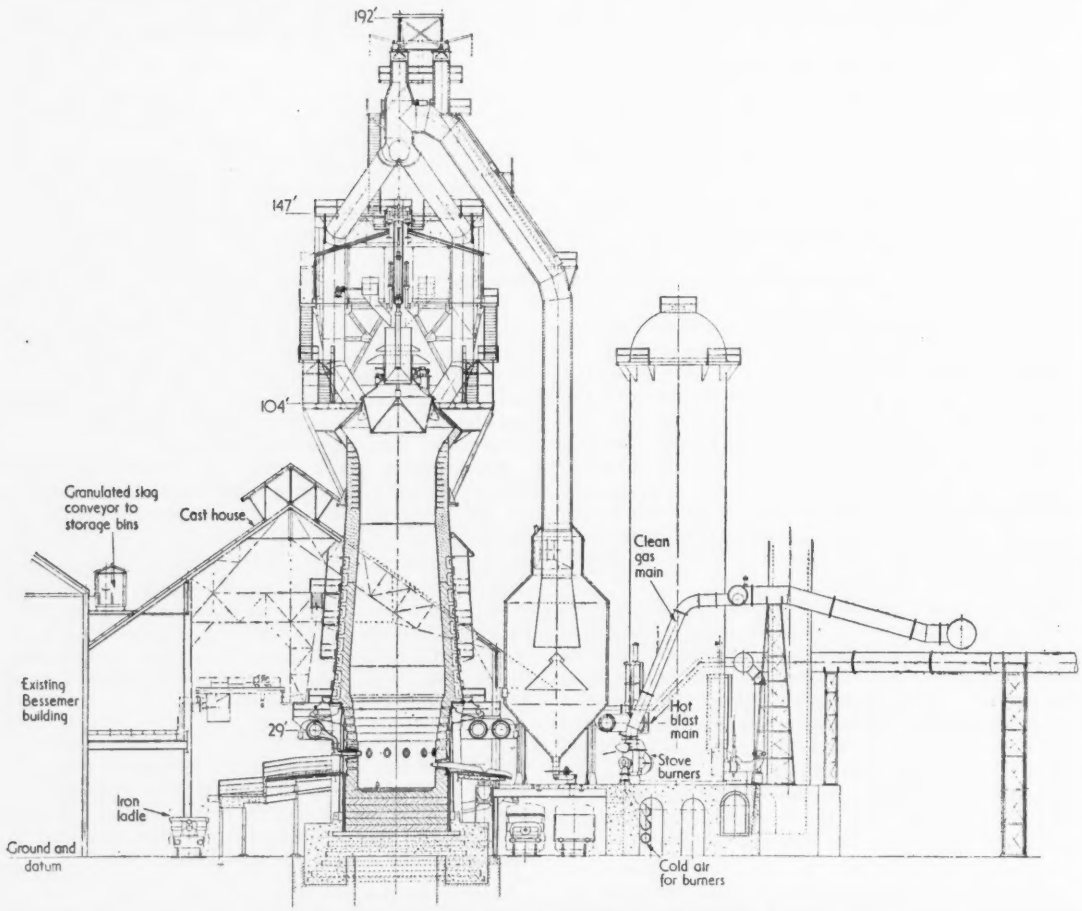


Fig. 1—Cross-section of the new No. 1 blast-furnace

been lowered on to them. No revolving takes place for the first pair of loads (one ore and one coke), but thereafter the small-bell hopper, after the load is in, revolves to give a 60° increment for each pair of loads, as follows : First pair zero, second pair 60°, third pair 120°, fourth pair 180°, fifth pair −120°, and sixth pair −60°.

The coke hoppers and the ore hoppers and feeders are shown on a larger scale in Figs. 5 and 6, respectively, and also in the photographs, Figs. 7 and 8.

The coke is fed into the hoppers fairly slowly by electromagnetically vibrated screen feeders, which are automatically slowed down and finally stopped when the pre-set weight is reached. Alternatively, the weighing mechanism can be put out of action and cut-off obtained by pre-set volume through an adjustable electrode projecting downwards into the hopper. Discharge, when initiated, takes place from the hoppers by means of high-capacity electromagnetically vibrated feeders arranged to run for just over 1 min., although the load is completely discharged in just under 1 min. As soon as this feeder stops, the filling feeder automatically starts again.

The ore, sinter, and additions, collected by the scale car in the usual way, are discharged simultaneously from both compartments into the ore feeder hopper. The ore feeder, of the apron-plate type, has the same volumetric rate of discharge as the coke discharge feeder and runs for about the same time. As soon as the feeder stops, the scale-car driver can refill it if he is ready.

The first problem to be solved was how to set the revolving hopper into operation at the right moment and how to stop a load in transit if the small bell has not already closed after its previous operation.

With a skip system the revolving is initiated at the end of hoisting by closing a switch geared to the winding engine. The succeeding operations of lowering and closing the small bell and the large bell (if it is then its turn to be operated) are in electrical sequence with the revolving operation and are independent of the operation of the next skip, except that the next rising

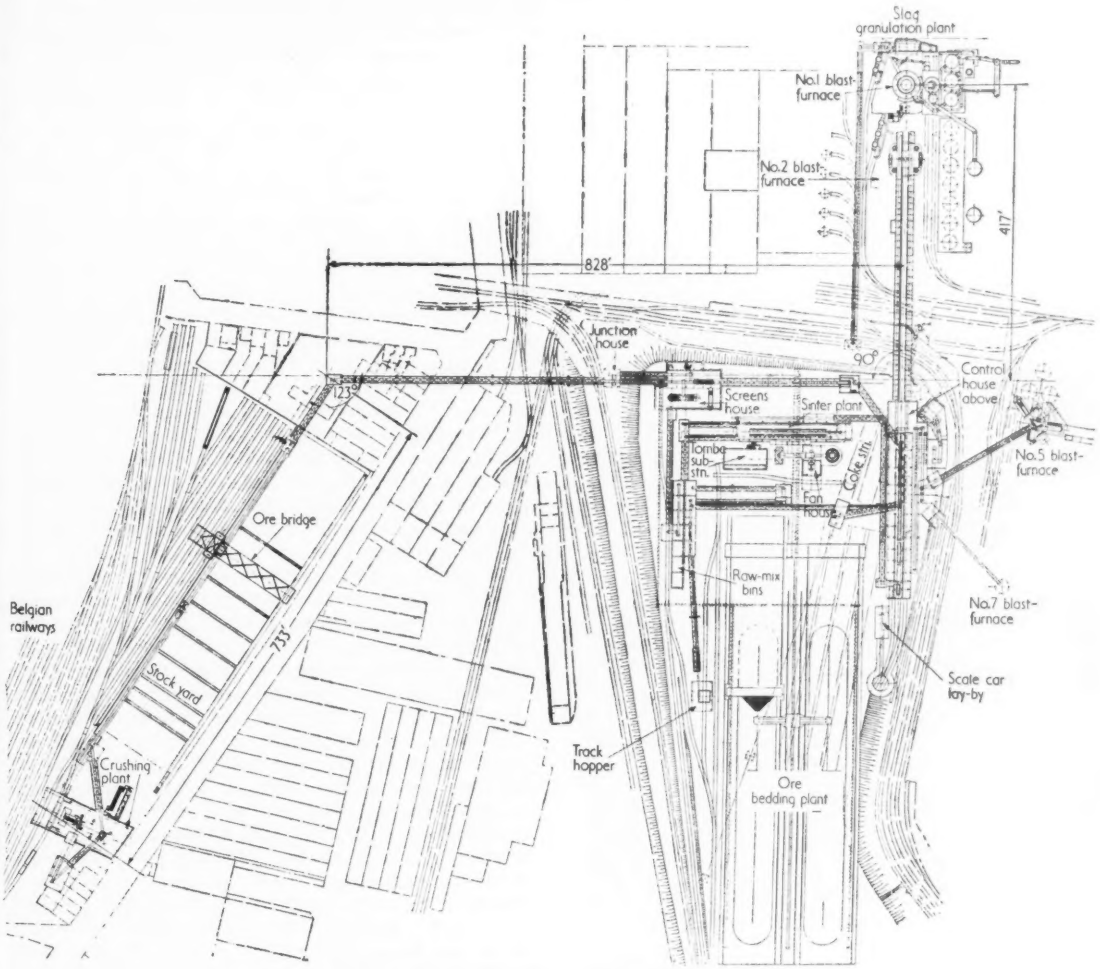


Fig. 3—Plan of ore-preparation and blast-furnace plant

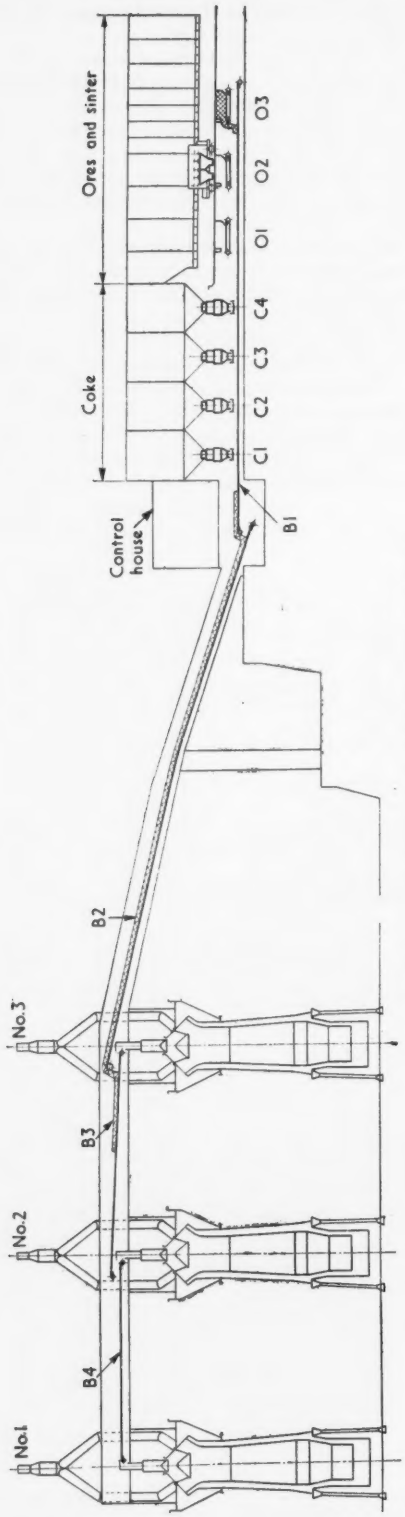


Fig. 4—Arrangement of bins, feeders, and belts

skip is stopped just before the start of tipping, if the small bell is not already closed after its previous operation. This stopping is effected by another switch, also geared to the winding engine. Skip travelling times and bell operation times are chosen to make this stopping a rare occurrence but, even so, a bell may be delayed in its final closing by having to be ' jigged ' to release trapped material. It was once the practice to locate these switches near the hoist top for direct operation by the skip itself, but they are now geared to the winding engine, where they are more accessible for maintenance. With the belt system, it was not considered satisfactory to operate them by the load itself. Striking levers or photo-electric cells, for example, could be operated at the wrong time by an odd piece of material on the belt.

The method used is the same in principle as that for the geared switches on the winding engines. Switches are operated by a device that runs in accordance with the distance travelled by the belts. An electric generator is geared to the tail pulley—not a drive pulley, which might slip—of the longest belt, the elevating belt *B*2 (Fig. 4). Wired to it is a follower motor which rotates exactly in synchronism with it at whatever speed it is running. This motor, located in a central control house, is geared to a shaft driving, through bevel gears, six other shafts—one for each of the loads making up a complete round of charges of an ore and a coke for each furnace (*see* Fig. 9). On each of these six shafts is an electromagnetic clutch and above each clutch is a spindle. Normally, the clutches are disengaged and the spindles are held stationary, but as soon as a clutch is energized the spindle above it will revolve in synchronism with the generator, but at a slower speed.

Attached to each spindle is a series of cams which, as they revolve, operate electrical contacts. One of them starts and stops a feeder, one gives clearance that the small bell has closed from its previous operation, and one initiates the revolving of the small-bell hopper. (This in turn initiates the independent sequence controlling the remainder of the top operations.) Other contacts ensure that the belts ahead of a load are running, and in the right direction, reversing them if they are not, and a final one de-energizes the clutch.

A spindle makes one complete revolution to deal with a load, and it stops, by the automatic de-energizing of its clutch, in its original position, ready to deal with the next similar load in the next complete round. By these means, therefore, when once started in transit, each load virtually controls, by its position, all subsequent operations to guide it to its destination.

To ensure that the belts are running, centrifugal switches are fitted to the tail pulleys of all belts ; those on the reversing belts are of the two-way type to ensure the correct direction of running.

All belts are driven by A.C. motors and belt speeds are therefore kept steady. This is important, because it is only from one of them, purposely the longest, that the drive for the controlling spindles is taken. Too much variation in the speeds of the other belts could not be tolerated, for a load in transit would not be in the position expected by its controller, and an event might take place either too early or too late.

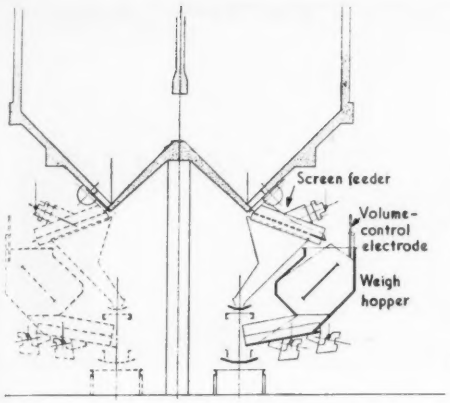


Fig. 5—Coke feeders

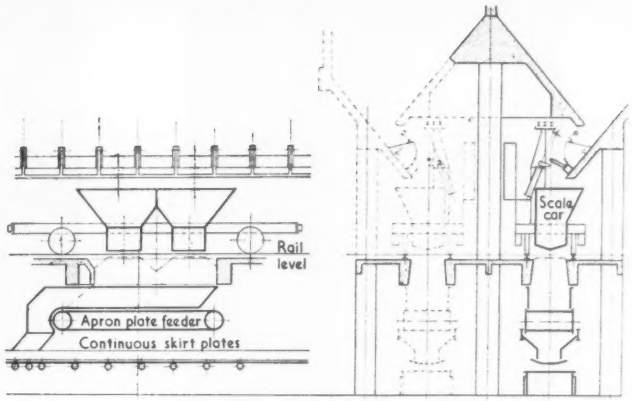


Fig. 6—Ore feeders

For three furnaces in operation together, loads will be despatched in similar sequences of six, each sequence made up of an ore load to each furnace in turn, followed by a coke load to each in turn. (The term 'ore' implies ores, sinter, and any necessary additions.)

Until the scale-car driver has operated a switch to show that he has filled the first of the ore feeder hoppers, and until the last load of the previous sequence is sufficiently on its way, the central operator will be unable to start the first feeder of a sequence. Similarly, thereafter, the other controllers will not be started, even if the initiation contact from the previous controller has been made, until similar feeder-full contacts have been made. This guarantees that when a feeder starts it is really dealing with a load ; otherwise the motions could be gone through without a load.

Normally, all three ore-feeder-full contacts will already have been made before a sequence starts, and all three coke-feeder-full contacts made before the first coke load is required. As soon as the first ore feeder has discharged its load, the next load from the scale car can be put in, for the scale car should be ready and waiting, having had time to collect its load while the coke hoppers are being filled. It has sufficient time, with the ores being relatively dry and free-flowing, to collect the remaining ore loads of the series before the last of the coke hoppers is discharged. The scale-car discharge doors are electrically interlocked with the ore feeders to prevent refilling until the previous load has been cleared. The same ore feeder will normally be used each time for the same furnace so as to minimize the chance of mistakes, for each furnace will probably be on a different burden.

To make the charging system as flexible as possible, it was considered desirable to be able to couple any feeder to any controller. There would then be a choice of sequence in which the loads follow each other ; a variation of feeders would be possible ; spare feeders could be incorporated ; and changes would be possible in the event of feeder breakdowns.

How to do this, and to make the necessary adjustments for the different distances that the loads would have to travel from the different feeders, was another problem. The solution, however, was simple. All that was needed was to arrange for all feeders, except the one most remote from the furnaces, to be delayed in starting until a length of belt had passed under them equal to their distance from the remote feeder. The effect of this was equivalent to having all the feeders in the same place as the remote one. This remote feeder therefore became the base line for fixing the positions of all the operating cams on the controllers, with the exception of the cams for feeder starting and stopping ; these had to be separately and readily adjustable. This adjustment was to be performed automatically when a particular feeder was selected and electrically coupled to a controller.

The makers of the controllers met this requirement simply and effectively by incorporating, in each controller, a sun and planet gear to rotate the feeder starting and stopping cam. When the feeder selector lever on the front of the main control panel is turned to one of its several locking positions, it also turns this cam, through gearing, by the correct delay angle needed to suit the distance of the particular feeder selected. At the same time, another separate spindle, on which are mounted the coupling-up cams, is turned to the coupling-up position for the feeder selected.

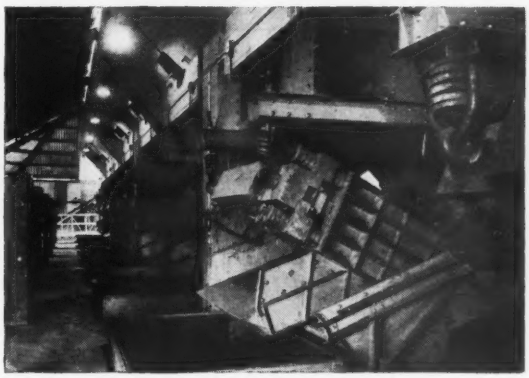


Fig. 7—Coke weigh hoppers and feeders

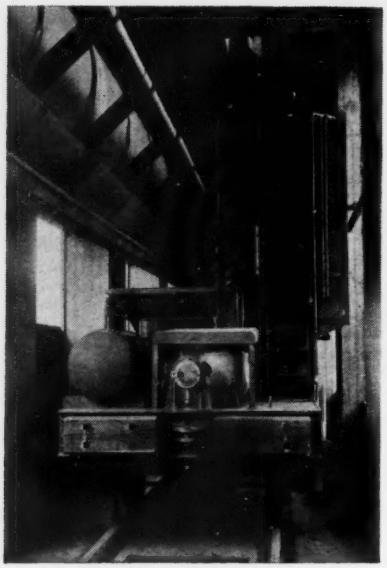


Fig. 8—Scale car and ore feeder hopper

The solution of this problem had another important result. Now that varying feeder distances did not, in effect, exist, the loads could follow each other at uniform spacing, more than one load could safely be in transit at a time, and the distance between any two loads need only be governed by the gap needed for the belts on the top of the furnaces to clear themselves and reverse. More efficient and economic use would thus be made of the system and a higher rate of charging would be possible. It was but a short step from this to incorporate an additional cam on each controller for each one to start the next automatically.

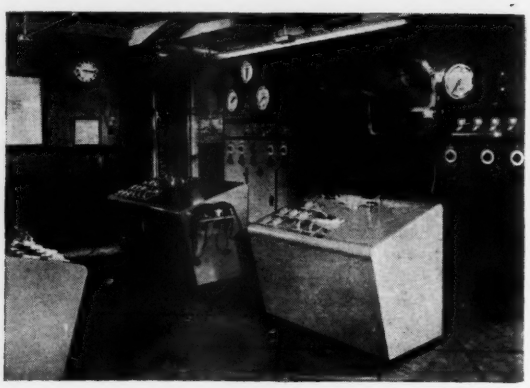


Fig. 10—Central control room

As already indicated, for normal operation of three furnaces, loads will be dispatched in a sequence of six. With only two furnaces they will be dispatched in a sequence of four. Sequencing can, however, be stopped at any time and odd loads charged by operating individual controllers.

If the small bell is not closed from its previous operation the whole charging system, including feeders, belts, and controllers, comes to a simultaneous standstill and cannot be started again until the delayed event takes place. A stoppage or failure of any part also stops the whole system.

CONTROL EQUIPMENT

When planning and locating the central control cabin it was considered that, for psychological reasons, the operator should be able to see the scale cars and discharge feeders, and this governed to some extent the position finally chosen. This provision is not really necessary, and there is a strong case for building a room of this kind away from the scene of operations.

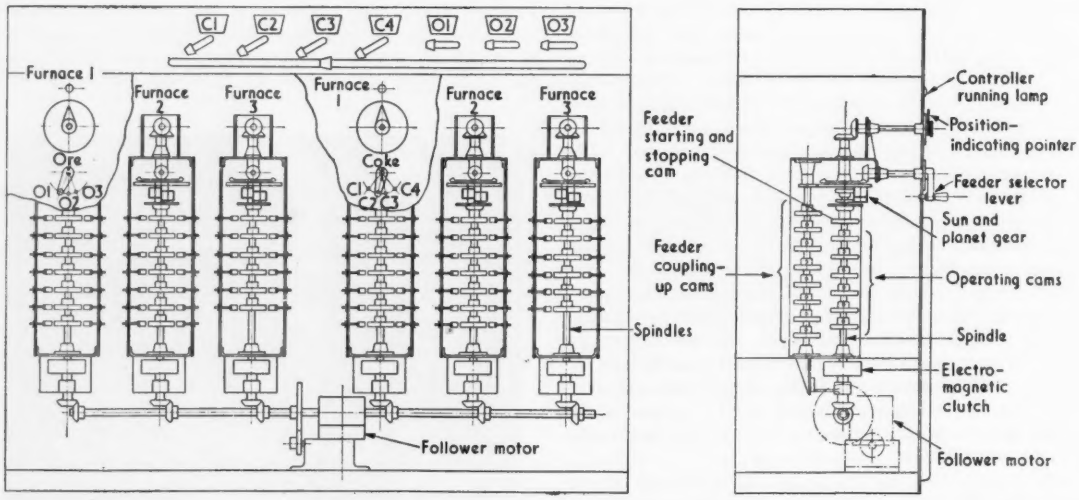
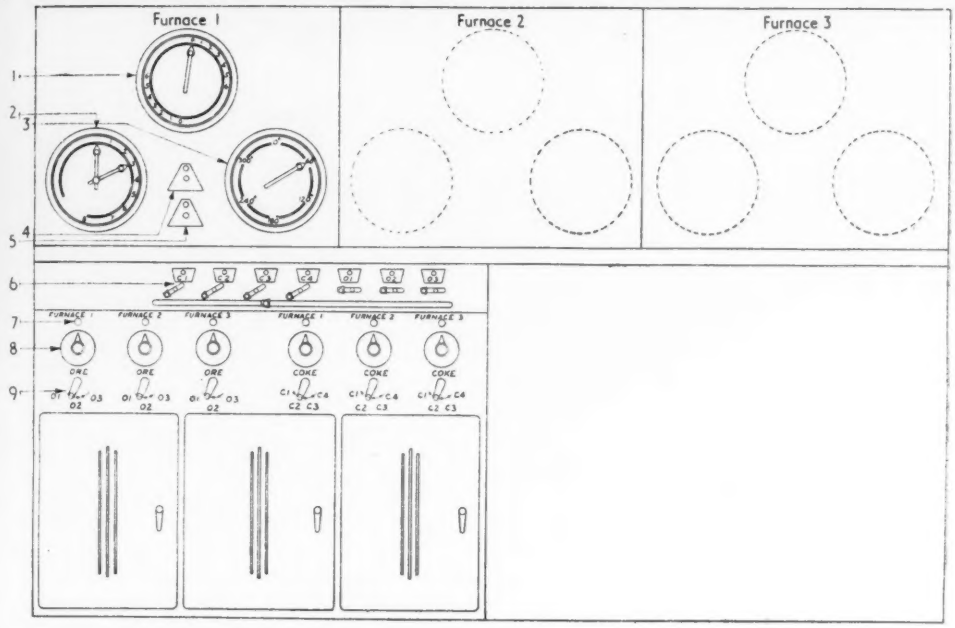
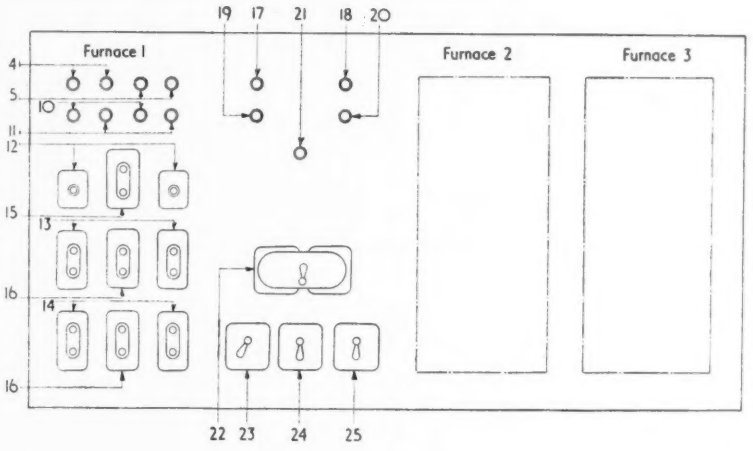
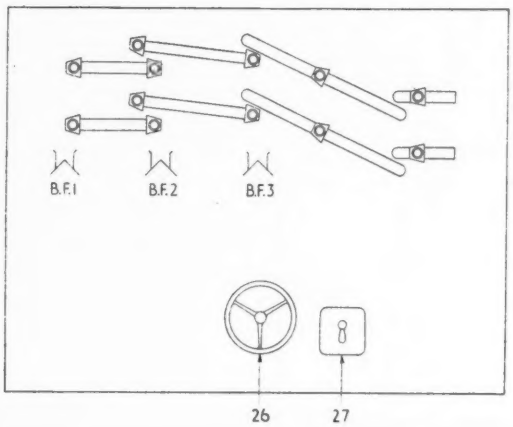


Fig. 9—Arrangement of charging controllers





(1) Bell cycle indicator
(2) Stockline indicator
(3) Distributor angle indicator
(4) Small bell position
(5) Large bell position
(6) Mimic diagram of coke and ore hoppers and feeders
(7) 'Controller running' signal lamps
(8) Controller position indicators
(9) Coke and ore feeder selectors
(10) 'Bell jigging' signal lamps
(11) 'Bell slack cable' signal lamps
(12) 'Reset-slack cable' push buttons
(13) Bell manual operation push buttons
(14) 'Stop jigging' and 'Reset' push buttons



(15) 'Include' and 'Exclude' extra loads from bell cycle push buttons
(16) Stockline manual control push buttons
(17) 'Sequence ready' signal lamp
(18) 'Sequence running' signal lamp
(19) 'Odd-load charging in operation' signal lamp
(20) 'Odd-load ready' signal lamp
(21) 'Odd-load running' signal lamp
(22) Odd-load selector switch
(23) 'Odd-load'–'sequences' selector switch
(24) 'Start odd-load' switch
(25) 'Start sequence' switch
(26) Charging-system selector
(27) Conveyor starting switch

Fig. 11—Arrangement of charging controls

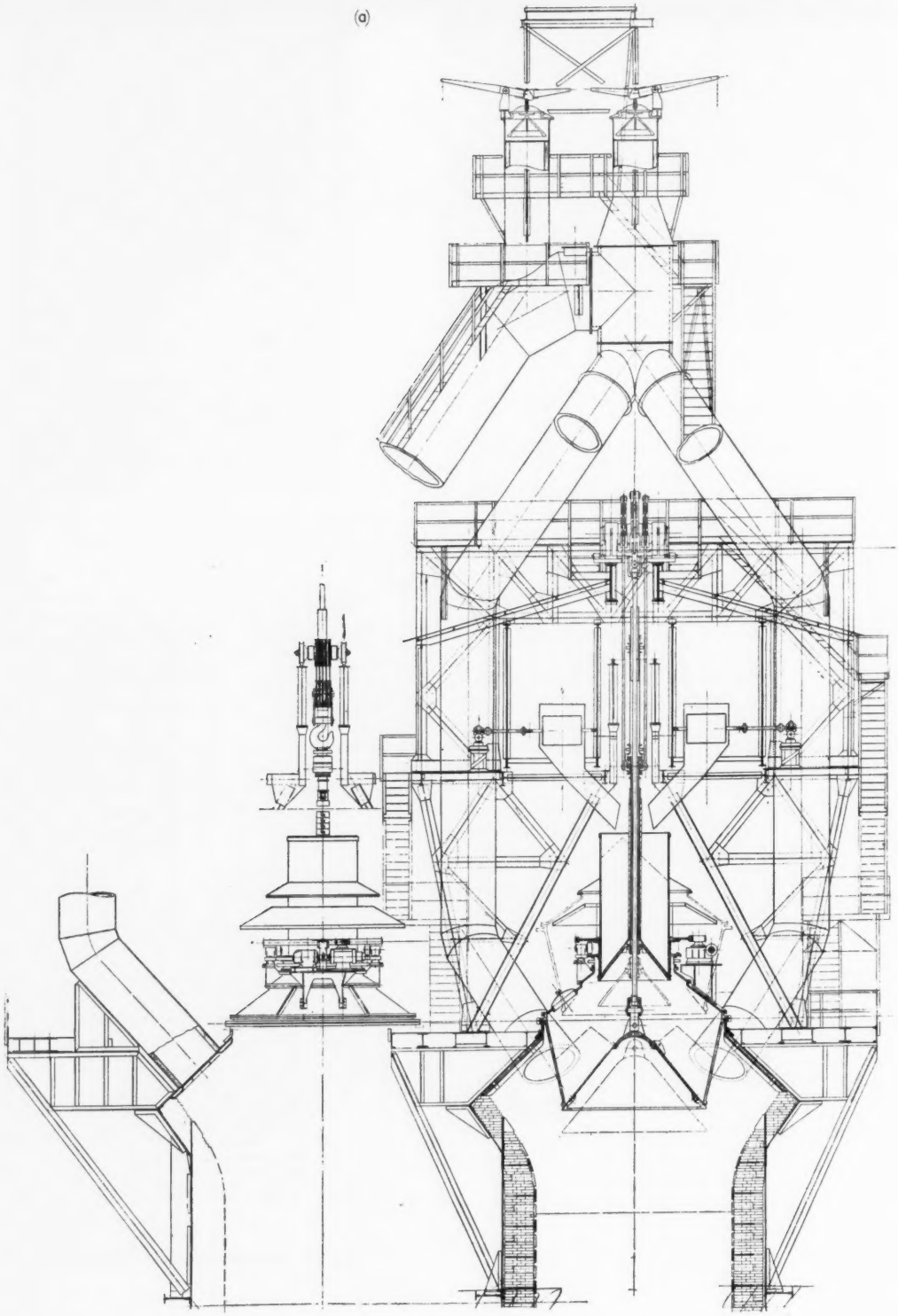


Fig. 12—Arrangement of furnace top

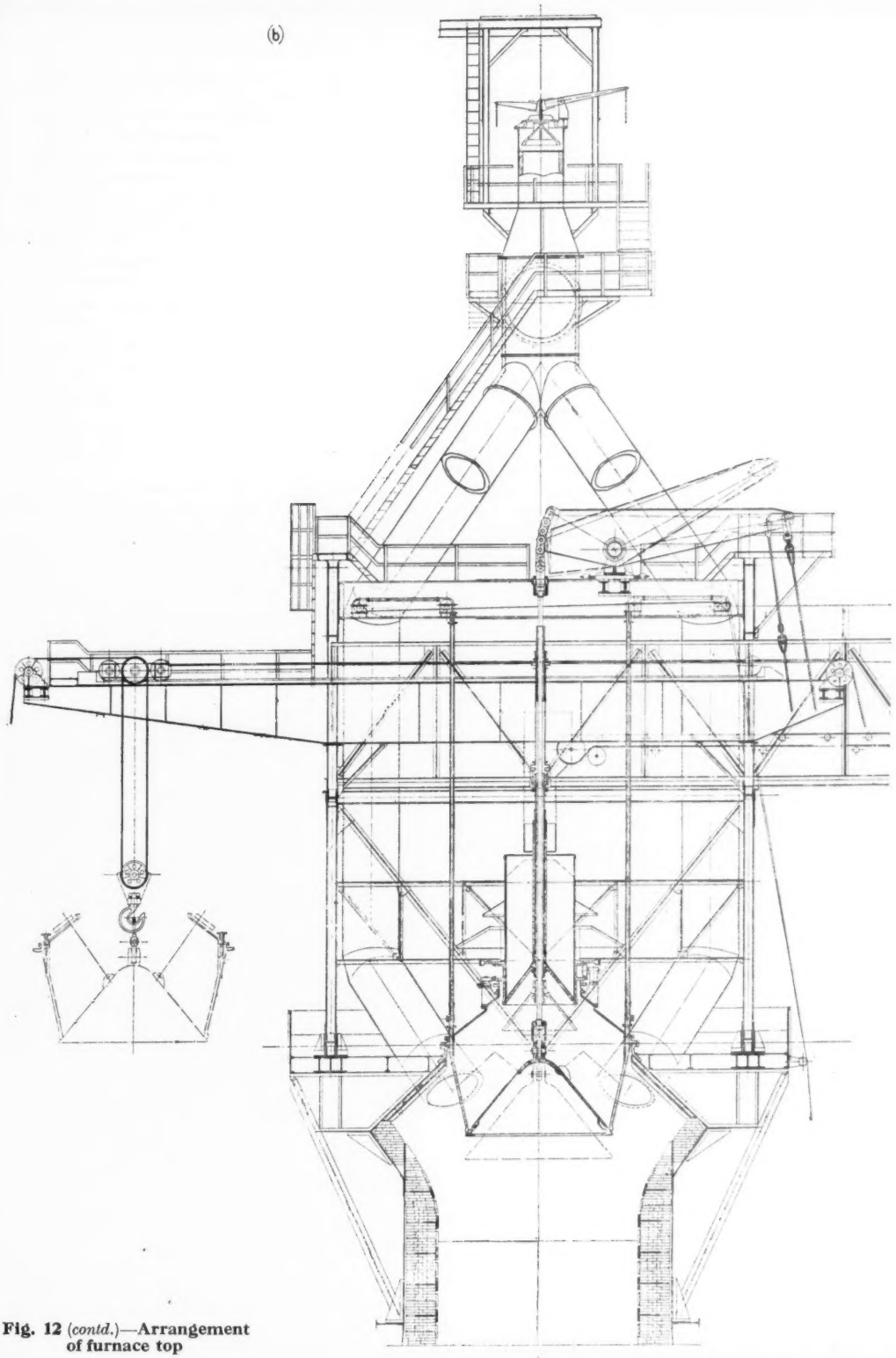


Fig. 12 (*contd.*)—**Arrangement of furnace top**

The general arrangement of the equipment in the cabin is shown in Fig. 10, and the location of the cabin itself in Figs. 3 and 4. Figure 11 shows the desks and control cubicles for furnaces 1, 2, and 3.

The charging controllers are housed in vertical cubicles facing the operator, and each controller is provided with (i) a selector switch (mentioned previously) for choosing the feeder to be used, (ii) a pointer driven by the controller spindle to indicate the approximate position in the charging cycle reached by that particular controller, and (iii) a signal lamp that lights when the controller is running.

The mimic diagram for the coke and ore hoppers and their associated feeders and the corresponding conveyors under the feeders are also provided on these cubicles with ' hopper full ' signal lamps and further lamps to indicate whether the feeders or conveyors are running or stationary. Stockline and charging indicators for the three furnaces are mounted above the controller cubicles.

Charging controls for the furnaces, together with essential controls and signal lamps for each furnace, are mounted on a desk facing the controller cubicles. The charging controls consist of switches for selecting the method of charging, starting switches, and signal lamps for indicating that the loads are ready to be, or are being, charged. Push buttons and signal lamps associated with individual furnaces largely concern abnormal operation, such as bell sticking or failure to re-seat. Manual controls for the bells and stockline rods are included but are rarely used.

The conveyor control desk carries a mimic diagram for the conveying system with ' running ' and ' stationary ' signal lamps, a selector switch for choosing the conveyor system to be used, and a switch for starting the conveyors. Push buttons for starting and stopping each of the conveyors for maintenance or testing purposes are also mounted on this desk, but are not used for normal charging and have been omitted from Fig. 11. The mimic diagram for the charging system serving furnaces 5 and 7, also on this desk, has been omitted to avoid confusion.

The contactor panels for controlling the furnace tops are housed in a room adjacent to the control room, and those for the conveyor drives are in a separate room above the control room, with a shallow basement between for housing cables.

The house itself is air-conditioned to provide reasonable working conditions and to exclude dust, particularly coke dust.

Provision has been made for modifying the sequence of operation of the furnace bells and revolving hopper from that described previously, although it is not anticipated that changes will be made. Selector switches for this purpose are mounted on the appropriate contactor panels.

CHARGING PROCEDURE

Instructions regarding the conveyor system and the coke hoppers and ore feeders to be used for each furnace are given to the charging operator, and the coke weighers are set to cut off at the required weight. Details of the burden composition and weight for each of the feeders are given to the scale-car operator. The charging operator then selects the charging system to be used on the conveyor control desk and starts the conveyors. He also selects, on the controller cubicle, the feeders to be used with each furnace.

As soon as power is available, the coke hoppers fill automatically and loads of ore are collected and dumped on each of the ore feeders by means of the scale car. When these operations are complete, the signal lamps on the controller cubicles light, automatically for coke, and by means of the scale-car driver's push buttons for ore. At this stage the sequence ' ready ' signal lamp lights and charging can be started by operating the appropriate switch. Charging continues automatically until all six loads have been delivered into their respective furnace hoppers, and when the last operation is complete the equipment is automatically left ready for the next charging operation. When a sequence of six loads has been initiated, the operator has nothing more to do except to watch the indicators until he receives the signal that the next sequence can start.

The group of three furnaces can be charged in this way by two men, one on the scale car and the other in the control room.

The working of the furnace-top equipment is independent of the charging system when revolving of the small-bell hopper has been initiated by a contact on the appropriate controller ; revolving, opening, and closing of the bells and the operation of the stock rods follow normal practice.

The electric control equipment might appear to be complicated but, when compared with that required for three skip-charged furnaces, there is little to choose between the two. Controls for the furnace tops and

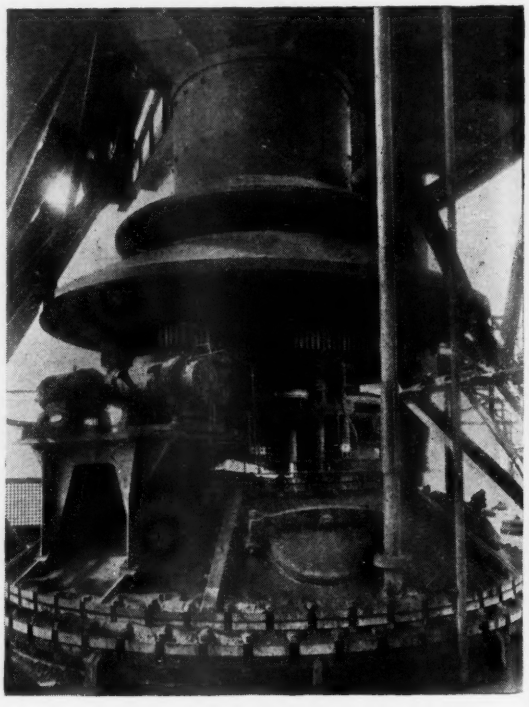


Fig. 13—Blast-furnace top

for the coke weigh hoppers are identical in each case, but in the belt-charging system the motors and starters for the various conveyors and feeders replace the skip hoist motors and controls.

The duplicate belt-charging system requires 14 induction motors and their starters, together with vibrators and starters for eight coke feeders (including two stand-by units). Of the motors, 12 are small squirrel-cage machines, with direct-on starters, and two are slip-ring motors. In a corresponding skip-charged plant, each furnace skip would require a D.C. hoist motor, possibly with a standby, and either a Ward–Leonard motor-generator set or D.C. accelerating and reversing contactors.

Sequencing of the belt system is a little more complicated than that required for skip hoists, but most of this work is carried out by the master controllers, which have proved to be both accurate and reliable.

FURNACE-TOP ARRANGEMENT

The arrangement of the belts in relation to the gas uptakes, the supporting structure for the bell operating levers, and the gantry girders for the bell changing trolley is shown in Fig. 12. The bell changing trolley can lift, as one assembly, the large bell, the large hopper, and the gas seal. The small-bell equipment is also lifted as one assembly, comprising the bell, the bell rod, the ball-bearing on top of the rod, the revolving hopper with its supporting and guide rollers, and the fixed ring below on which are mounted the roller brackets. All these parts are of one-piece construction, and not, as is usual, in two or more parts, and they are therefore stronger and lighter and have much less machining on them.

During dismantling, the large bell is first hooked up to the gas seal through the manholes in it. The large-bell rod is then lifted out through the hollow small-bell rod, leaving the top of the furnace clear for the dismantling trolley to go right through for lowering the assemblies to the cast-house floor on one side and to the furnace-top platform on the other.

New features introduced to prevent gas leakage are so effective that one is unaware, when at the top, that the furnace is on full wind. The seal round the revolving hopper is by two horizontal rubbing rings with flat surfaces, one of which is fixed, the other forming one flange face of a large expansion joint which is bolted to the hopper by its other flange and therefore revolves with it. This construction allows sideways floating of the hopper. The hopper is supported and guided by vertical and horizontal rollers and is constrained by them to limited movement in both vertical directions as well as horizontally. The expansion joint is therefore always under compression, maintaining pressure between the flat surfaces, which are grease-lubricated. The furnace top is shown in Fig. 13.

The gap between the bell rods has also been sealed. A neat-fitting gland is used, but its housing is flexibly connected to the top of the small-bell rod so that there is complete freedom for the movements required, relative rotation, relative up and down, and a sideways one which permits the rods to rock slightly to ensure that the bells are properly closed on their seating surfaces. The test rods are completely enclosed.

OPERATING RESULTS AND COMPARATIVE COSTS

Although, as mentioned earlier, only one furnace is so far in operation, most of the equipment for charging the three furnaces has been installed and is working in a series of four loads, practically as described for the six. This, coupled with the fact that another furnace, No. 5, is being charged similarly, both furnaces now having been in operation for three years, leaves no doubt of the ability of the equipment to do the job for which it was designed.

The capital cost of a duplicated system for charging two furnaces is about the same as for orthodox skip charging ; it is more expensive for a single-furnace plant, and is cheaper for three or more furnaces.

The plant installed has given very little trouble. In fact, over the last three years the functioning of the plant has been entirely satisfactory, with no major incidents, and has exceeded the most optimistic hopes.

Acknowledgments

The author thanks S. A. John Cockerill for permission to publish this paper, and wishes to record that the successful design and operation of the plant is largely due to their whole-hearted co-operation. He also thanks his colleagues who assisted in the preparation of the paper.

Central Greasing Station for Electric Overhead Travelling Cranes

By L. R. Evans, M.I.Mech.E.

THE method of lubricating electric overhead travelling cranes from a central greasing station has recently been introduced in some steelworks, but the system described in this note, which has been installed in several departments of the English Steel Corporation, Ltd., Sheffield, and is to be a standard for all their works, has features that have not previously been used. A description of the installation, which serves the cranes in two parallel and adjacent bays, may be of interest.

A keg of grease (*see* Fig. 1) as received from the

Manuscript received 8th July, 1953.

Mr. Evans is Chief Maintenance Engineer with the English Steel Corporation, Ltd., Sheffield.

Fig. 1—Keg of grease and grease pump

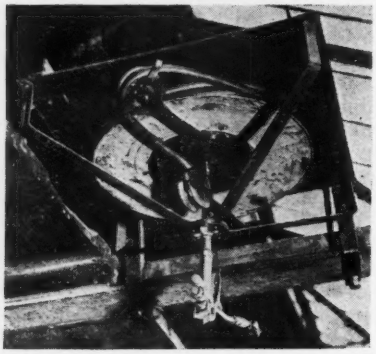


Fig. 2—Reeling drum mounted on shop roof truss

manufacturers is placed at the base of the shop column where the greasing station is to be installed. A special lid in place of that supplied is fixed on the keg and locked in position. An air-operated grease pump is placed on the lid with the pumping cylinder passing through the grease to the bottom of the keg. The pump takes its supply from the works' compressed-air service, the pressure being reduced to about 45 lb./sq. in. by the variable reducing valve which is built into the pump. This pressure can be varied to suit the height to which the grease has to be lifted. A suitable water separator and trap is fixed in the air pipeline to the pump.

From the pump the grease is taken up a $\frac{3}{4}$-in. dia. pipe attached to the shop column, and at roof-truss

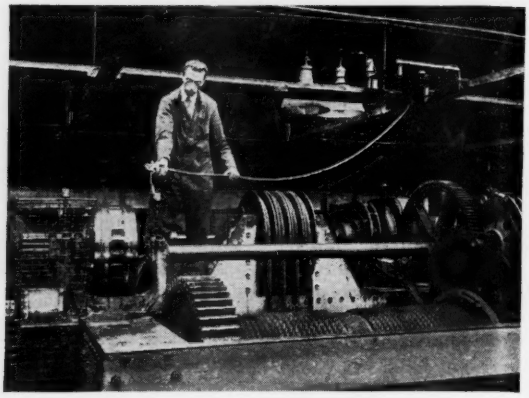


Fig. 3—Greasing 100-ton electric overhead travelling crane crab

level branches are taken from it to run along the roof truss in each bay. The pipes are connected to reeling drums (*see* Fig. 2), which are mounted on the roof trusses in the centre of the bays. Each reeling drum has wound on it 50 ft. of high-pressure rubber hose to allow greasing to be carried out on all parts of the crane by means of a pistol-type dispensing valve attached to the end of the hose. The hose is automatically wound back on the drum by means of a spring-loaded coiling device. The reeling drums are of standard design, usually used as cable-reeling drums for small electric hoists on runway tracks or jib cranes. The only modification made to them is to increase the side-plate diameters to allow for the extra length of hose.

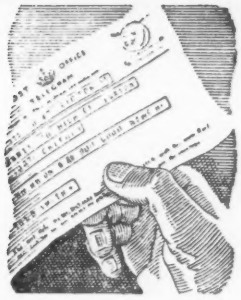
When a crane has to be greased it is brought up to a point below the reeling drum (*see* Fig. 3). The crane driver opens an air valve placed on the shop column at crane-track height which puts into operation the grease pump at shop-floor level. He takes the grease gun and, by pulling on the hose, uncoils it and greases all points by means of grease nipples or nipple-fed lubricators, which can be adjusted to give the rate of feed required. After greasing, the hose coils back automatically on to the drum. The same equipment can be used for refilling the grease reservoir on cranes with mechanical lubricating systems.

With this installation the greasing time is reduced by two-thirds of that taken for normal hand lubrication with grease gun and hand-filled stauffers, and risk of contamination of the grease is reduced.

The reduced time taken makes it practicable and economical to employ specially trained lubrication hands to look after a large number of cranes, and thus to improve the efficiency and regularity of the operation.

The cost of supplying and erecting the installation described is £200.

N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Annual General Meeting, 1954

The **Annual General Meeting** of The Iron and Steel Institute will be held at 4 Grosvenor Gardens, London, S.W.1, on **Wednesday and Thursday, 26th and 27th May, 1954.** The Annual Dinner will be held on the evening of 26th May. Details of the programme will be given in a later issue of the *Journal*.

Changes on Council

Mr. A. H. INGEN HOUSZ, of the Royal Netherlands Iron and Steel Works Ltd., has been nominated to be an Honorary Vice-President.

The following have accepted invitations to serve as Honorary Members of Council during their periods of office:

Mr. D. L. BLEWETT, President of the Swansea and District Metallurgical Society

Mr. H. J. MILLER, President of the Liverpool Metallurgical Society.

Special Meeting in Sweden, 1954

At the kind invitation of the Board of Jernkontoret a special meeting of The Iron and Steel Institute will be held in Sweden from **5th to 19th June, 1954.**

For the convenience of those members who do not wish to attend over the whole period, the meeting has been divided into three parts.

The proposed programme is as follows:

First Part (Saturday, 5th June, to Thursday, 10th June)

Preliminary to the main meeting, visits to works and other places of interest will be made at Gothenburg, Västerås, and Surahammar. (Departure from London by steamer on 5th June; Gothenburg 7th June and 8th June; Västerås etc. 9th June; arrival Stockholm evening 9th June.)

Second Part (Thursday, 10th June, to Saturday, 12th June)

The main meeting in Stockholm will begin with a reception at Jernkontoret on the evening of 10th June. There will be a technical session on the morning of Saturday, 12th June. Visits to works and places of interest will be arranged and evening entertainments provided. (Departure from London by steamer 8th June; arrival at Stockholm, *via* Gothenburg, afternoon 10th June.)

Note: Members wishing to return by steamer *via* Gothenburg can leave Stockholm on Tuesday, 15th June.

Arrangements will be made for those who prefer to travel by air to join the above parties at either Gothenburg or Stockholm; they can return from Stockholm on Sunday, 13th June, or later.

Third Part (Sunday, 13th June, to Saturday, 19th June)

After the main meeting, there will be three alternative excursions, by special sleeping car trains, to Swedish industrial centres. The first two of these, to Värmland (Hellefors, Uddeholm, Bofors, etc.) and Dalecarlia (Sandviken, Domnarfvet, Falun, Fagersta, etc.), will leave Stockholm on the evening of Sunday, 13th June, and return to Stockholm on Thursday, 17th June, or to Gothenburg for connection to steamer arriving London on 19th June. The third excursion, to Lappland (Narvik, Kiruna, Gällivare, Lulea, etc.), will leave Stockholm on the morning of Sunday, 13th June, and return to Stockholm on Friday, 18th June, to connect with the steamer leaving Gothenburg on 19th June and arriving London on the morning of 21st June.

Note: Facilities will be provided for those who wish to stay longer. Arrangements will be made for those who prefer to return by air after the excursions.

Full particulars of the programme will be given in later issues of the *Journal* and a circular will be sent to all members early in the new year.

NEWS OF MEMBERS

▶ Professor P. G. BASTIEN delivered the opening Lecture at the International Foundry Congress, held in Paris in September.

▶ Mr. E. COHEN has left the Normanby Laboratories of B.I.S.R.A. to take up an appointment as Lecturer in the Department of Mineral Dressing at the Imperial College of Science and Technology.

▶ Mr. A. E. EL-MEHAIRY has been awarded the degree of Ph.D. in the Faculty of Engineering of the University of London.

▶ Dr. A. T. GREEN, O.B.E., has been elected President of the British Ceramic Society.

▶ Mr. R. J. HARBORD has joined John Lysaghts (Scunthorpe) Ltd., as a Student Metallurgist.

▶ Dr. N. P. INGLIS has been appointed to the Executive Committee of the Aluminium Development Association.

▶ Mr. R. T. KEENE has been appointed Technical Officer to the Transportation Directorate of the War Office, and is stationed at Longmoor Camp, Liss, Hants.

▶ Dr. N. H. POLAKOWSKI has left the University College of Swansea to join the Armzen Co., Waterbury, Conn., U.S.A. His present business address is Sendzimir Ltd., 75 Grosvenor Street, London, W.1.

▶ Mr. G. J. SHAW has left the University of Birmingham and is employed as a Metallurgist with Coneygre Foundry Ltd., Tipton, Staffs.

▶ Mr. E. M. SUMMERS has been appointed Furnace General Manager of the Stanton Ironworks Co., Ltd.

Obituary

Mr. Louis RIPLEY, O.B.E., formerly Director of Blackett Hutton and Co., on 5th October, 1953.

Mr. W. SINGLETON, of the Firth Co., Ltd., Warrington, on 11th September, 1953.

Mr. C. B. C. STOREY, of Farnham, Surrey, in September, 1953.

A. H. Norris

J. H. Rendall

CONTRIBUTORS TO THE JOURNAL

A. H. Norris—In charge of the Cogging and Continuous Mills at John Lysaght's Scunthorpe Works Ltd.

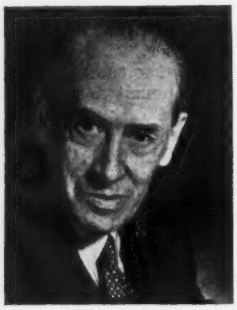
Mr. Norris was born in 1915 and was educated at Cheltenham College. He joined John Lysaght Ltd. in 1934, and held the post of Mill Manager at the Scunthorpe Works from 1943 until he took up his present appointment in 1950. He was elected a Member of The Iron and Steel Institute in 1937 and is now a Vice-President of the Lincolnshire Iron and Steel Institute.

J. H. Rendall, B.Sc.—Senior Scientific Officer in the Metallurgy Division of the National Physical Laboratory.

Mr. Rendall was born at Shanghai, China, in 1920. He received his technical education at the Royal School of Mines, graduating with Honours in Metallurgy in 1941. In the same year he was appointed Materials Officer in the Department of Tank Design, where he assisted in the testing, inspection, and development of armour castings for tanks. In 1945 he became a Research Metallurgist with F. H. Lloyd and Co., Ltd., working on electric steelmaking and foundry sands. Mr. Rendall took up his present appointment in 1949 and has since been engaged in research on powder metallurgy and refractory materials.

Vaughan H. Stott, D.Sc.—On the staff of the Metallurgy Division of the National Physical Laboratory.

Dr. Stott was born in 1894, and graduated with honours in Chemistry in 1914. He joined the research staff of the Richmond Gas Stove and Meter Co. in 1915, and entered the Metallurgy Division of the National Physical Laboratory in 1917 to carry out researches connected with the manufacture of optical glass. This work was discontinued in 1926, and for some years Dr. Stott was occupied with metallurgical problems, including the production of large single crystals of various metals, and determinations of the increase in the internal energy of aluminium and of copper resulting from wire drawing. Since 1935, Dr. Stott, in addition to other activities, has been responsible for the production of special refractory ware for metallurgical and other researches involving high temperatures.



V. H. Stott

IRON AND STEEL ENGINEERS GROUP

The **Twenty-Fourth Meeting** of the Iron and Steel Engineers Group will be held at 4 Grosvenor Gardens, London, S.W.1, on **Thursday, 10th December, 1953.** A Buffet Luncheon will be held in the Library.

The following is the detailed programme:

10.30 A.M.–12.45 P.M.—Discussion on:
"*Belt-Charged Blast-Furnaces of S.A. John Cockerill, Belgium,*" by G. Hookham (John Miles and Partners (London), Ltd.) (*see* this issue, pp. 409–419)

12.45–2.0 P.M.—Buffet Luncheon

2.0–4.0 P.M.—Discussion on:
"*The Ironmaking Plant at the Shotton Works of John Summers and Sons, Ltd.*," by J. F. R. Jones and A. Walker (John Summers and Sons, Ltd.) (*see* November, 1953, issue, pp. 313–321).

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

41st Steelmaking Conference

The 41st Steelmaking Conference was held at Ashorne Hill, on 23rd–24th September, 1953. Dr. T. P. Colclough, C.B.E., was in the Chair, and Mr. R. W. Evans was Vice-Chairman. The Conference was divided into three sessions, the first being devoted to a description of steelmaking research at the Institut de Recherches de la Sidérurgie, given by Monsieur Husson, Head of the Steelmaking Research Department of I.R.S.I.D. He spoke on the basic Bessemer process and reported researches on such matters as the pre-refining of pig iron, the solidification of rimming steels, the investigation of the life of ingot moulds, and the use of oxygen in the open-hearth process.

The second session was devoted to "*Furnace Design in Relation to Refractory Consumption and Fuel Economy,*" and the speakers were Mr. S. W. Pearson, Mr. S. Senior, Dr. A. J. Kesterton, and Mr. W. M. Fern.

In the third session, Dr. G. W. C. Allan described recent developments in gas-producer operation, and Mr. G. R. Bashforth spoke on the modern gas-producer installation of the new open-hearth melting shop at the Round Oak Steelworks. During discussion it was stressed that, despite the advent of oil-firing, producer gas is still a major fuel for production in this country, and that recent developments in producer design and operation lead to greater efficiency and economy in its use. It has been proposed that this subject shall form the basis of a discussion at a Steelmaking Conference in 1955.

Seventh Chemists' Conference

The Seventh Chemists' Conference, held at Ashorne Hill on 5th–7th October, 1953, was attended by the record number of over 160 people. During the first evening Mr. J. O. Lay, Secretary of the Methods of Analysis Committee, took the Chair, while Dr. G. J. Hodsman delivered a paper on "*Modern Precision Weighing*" and answered questions. This informal session was arranged in conjunction with an exhibition of analytical balances which was open throughout the Conference.

The three main sessions were presided over by Dr. E. Gregory, Chairman of the Methods of Analysis Committee, who opened the Conference with a review of the year's work. Among other items, proposals have been drawn up for the routine analysis of iron ore, and these were outlined by Mr. G. E. Speight, who indicated that although many classical methods were still unsurpassed, advances in technique over recent years permitted the introduction of some alternative and more reliable methods into such a scheme of analysis. As an extension of the researches on absorptiometric analysis, Mr. H. G. Short described a procedure by which accurate determinations at or near the 100% content level could be

made, by precise balancing of colour intensity for the major proportion of the element sought and measurement of the remainder by difference.

In the second session Mr. B. Bagshawe reviewed the recommended procedure for the determination of sulphur in steel and drew attention to the precautions necessary to achieve reproducibility, Mr. S. Harrison dealt with the absorptiometric determination of cobalt using nitroso-R-salt, and Messrs. K. Dixon and J. H. Oldfield presented papers on spectrographic analysis. The former explained techniques for the decomposition of a sample to form a homogeneous solution and for the introduction of this solution into a discharge gap, giving examples of the reproducibility obtainable and the essential conditions of operation, whilst the latter showed how the standard method for the spectrographic analysis of low-alloy steels had been modified, chiefly by changing the excitation conditions, for the determination of certain elements as residuals in mild steel. This session closed with an account by Mr. R. C. Chirnside of the development of a conductimetric apparatus for the determination of carbon in steel.

The special paper in the final session dealt with chemical control in the heat-treatment of steel and was delivered by Dr. I. Jenkins. The speaker demonstrated the application of thermodynamics to the prediction of reaction potentials and various means of adjusting atmospheres for particular purposes, with examples of industrial processes employing these principles.

AFFILIATED LOCAL SOCIETIES

Cleveland Institution of Engineers

The list of Officers for the Session 1953–54 is as follows:

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Vice-Presidents
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C. MOODY G. B. THOMAS
N. C. LAKE

Swansea and District Metallurgical Society

A joint meeting of the Swansea and District Metallurgical Society and The Iron and Steel Institute will be held in the Central Library, Swansea, on Tuesday, 5th January, 1954. Mr. D. L. Blewett, J.P., President of the Society, will be in the Chair, and Dr. W. R. Maddocks (Sheffield University) will lecture on Slags.

NEWS OF SCIENCE AND INDUSTRY

Platinum Metals Exhibition

A Platinum Metals Exhibition was held by the Institution of Metallurgists, at Grosvenor House, London, W.1, on 22nd–24th October, 1953. The Exhibition, which was opened by H.R.H. The Duke of Edinburgh, was held to commemorate William Hyde Wollaston's announcement in 1803 of his discovery of palladium, and it comprised both historical exhibits connected with the early history of platinum metals and many examples of present-day applications.

Beilby Memorial Awards

From the interest derived from the invested capital of the Sir George Beilby Memorial Fund, at intervals to be determined by the Administrators representing the Royal Institute of Chemistry, the Society of Chemical Industry, and the Institute of Metals, awards are made to British investigators in science to mark appreciation of records of distinguished work. Preference is given to investigations relating to the special interests of Sir George Beilby, including problems connected with fuel economy, chemical engineering, and metallurgy, and awards are made, not on the result of any competition, but in recognition of continuous work of exceptional merit, bearing evidence of distinct advancement in science and practice.

In general, awards are not applicable to workers of established repute, but are granted as an encouragement to younger men who have done original independent work of exceptional merit over a period of years. The Administrators are empowered to make more than one award in a given year if work of sufficient merit by several candidates is brought to their notice. In 1952, one award of one hundred and fifty guineas was made to Mr. T. V. Arden (*see* June, 1953, issue of the *Journal*, p. 162).

Consideration will be given to the making of an award or awards from the Fund early in 1954, and the Administrators will therefore be glad to have their attention drawn to outstanding work of the nature indicated, by not later than 31st December, 1953. Communications on this matter should be accompanied by nine copies of a short statement of the candidate's career and of a list of references to papers or other works published by the candidate, independently or jointly, and should be addressed to the Convenor of the Administrators, Sir George Beilby Memorial Fund, Royal Institute of Chemistry, 30 Russell Square, London, W.C.1.

Westberg Metal Sampling Development

The British Steel Castings Research Association has announced the successful development of a rotary metal sampling device, based upon a design of the late Mr. S. Westberg of Rotherham, which enables furnace samples of steel or other metals to be produced in finely granulated or divided form directly from the liquid state and without the necessity for drilling operations. This is done by pouring the liquid sample on to a rotating copper disc, which disperses the metal centrifugally on the internal periphery of a surrounding metal bowl. Prevention from oxidation during sampling is achieved by providing a high-purity nitrogen or inert gas atmosphere in the dispersion cavity of the machine.

Extended field trials on the Westberg sampling device have demonstrated the necessary degree of reliability and correlation with analyses performed on orthodox drilled samples, not only in respect of the normal elements—carbon, sulphur, silicon, phosphorus, and manganese—but also of nickel, chromium, molybdenum, and tungsten, over a relatively wide range. These field trials have been conducted by the British Steel Castings Research Association in conjunction with Messrs. Westberg Developments Ltd., Rotherham, who are now manufacturing and marketing the equipment.

Investigation into Powder Metallurgy

Under the Technical Assistance scheme of the Organization for European Economic Co-operation, a team of experts recently visited the United States to study the latest uses and production methods in powder metallurgy.

The team comprised 28 experts from Belgium, Denmark, France, Germany, Italy, the Netherlands, and the U.K.

British Iron and Steel Corporation

Sir Charles Bruce-Gardner, chairman of John Lysaght Ltd., and a director of the Steel Company of Wales Ltd. and of Guest Keen and Nettlefolds Ltd., has been appointed chairman of the British Iron and Steel Corporation, in succession to the Earl of Dudley.

Precautions in the Use of Ionizing Radiations

A pamphlet on health and safety precautions in the use of ionizing radiations in industry has been issued by the Factory Department of the Ministry of Labour and National Service. It serves as a companion to two other official publications: "*Recommendations of the British X-ray and Radium Protection Committee*," and the Medical Research Council's "*Introductory Manual on the Control of Health Hazards from Radioactive Materials*," which deal with precautions necessary in hospitals and in university and research laboratories. The pamphlet, which is entitled "*Precautions in the Use of Ionizing Radiations in Industry*," is obtainable from H.M.S.O. or through any bookseller, price 2*s.* 0*d.*

Index to University Theses

ASLIB have recently published the first volume of a new series, "*Index to Theses accepted for Higher Degrees in the Universities of Great Britain and Ireland.*" In this country, the university thesis exists in typescript only and, once accepted, often becomes merely an unrecorded archive. This series, which is intended to become an annual national bibliography, covers all subjects, and each entry contains the title of the thesis, the author's name and university, and a note indicating availability to the public. Volume 1, edited by Mr. P. D. Record, covers the period 1950–51 and lists some 2200 theses. It is obtainable from ASLIB, price 25*s.* (postage 6*d.*).

Conditions in the Drop Forging Industry

The Report of the Committee on Conditions in the Drop Forging Industry has been published, and is obtainable from H.M.S.O., or through any bookseller, price 1*s.* 6*d.*

CORRIGENDUM

Determination of Copper

In Table V of the paper entitled "*The Determination of Copper in Iron and Steel*," by the Methods of Analysis Committee (August, 1953, issue of the *Journal*, p. 337), the heading is given as "Thiosulphate Method—App. 1." It has been pointed out that this should read "Thiocyanate Method—App. 1."

DIARY

1st Dec.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Specifications—Friends or Foes?*" by S. Barraclough—B.I.S.R.A., Hoyle Street, Sheffield, 7.0 P.M.

1st Dec.—INSTITUTION OF STRUCTURAL ENGINEERS—"*Reconstruction of a Soaking-Pit Building*," by H. C. Husband and K. H. Best—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 6.30 P.M.

2nd Dec.—INSTITUTION OF ELECTRICAL ENGINEERS—"*Electrical Equipment of a Blooming Mill*," by G. G. Nicholson—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 6.30 P.M.

3rd Dec.—SOCIETY OF CHEMICAL INDUSTRY (Chemical Engineering Group) (Joint meeting with the Institute of Metals)—"*Metallurgical Trends of Interest to the Chemical Industry*," by L. Rotherham—Bristol.

3rd Dec.—LEEDS METALLURGICAL SOCIETY—"*Some Modern Copper-Base Alloys*," by E. Voce—Chemistry Department, The University, Leeds 2, 7.15 P.M.

4th Dec.—INSTITUTION OF MECHANICAL ENGINEERS—"*Comparative High-Temperature Properties of British and American Steels*," by W. E. Bardgett and C. L. Clark; and "*A Critical Examination of Procedures Used in Britain and the United States to Determine Creep Stresses for the Design of Power Plant for Long Life at High Temperatures*," by R. W. Bailey—Storey's Gate, St. James's Park, London, S.W.1, 5.30 P.M.

7th Dec.—CLEVELAND INSTITUTION OF ENGINEERS—"*Gasholders, with Special Reference to the Steel Industry*," by T. H. Riley—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 6.30 P.M.

7th Dec.—SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS (Joint meeting with the Institute of British Foundrymen)—"*Shell Moulding*," by J. Fallows—Sheffield College of Commerce and Technology, Pond Street, Sheffield, 7.30 P.M.

8th Dec.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Ladle Linings*," by J. Mackenzie—B.I.S.R.A., Hoyle Street, Sheffield, 7.0 P.M.

8th Dec.—EAST MIDLANDS METALLURGICAL SOCIETY—"*Powder Metallurgy*," by L. Harrison—Nottingham and District Technical College, Shakespeare Street, Nottingham, 7.30 P.M.

10th Dec. — LIVERPOOL METALLURGICAL SOCIETY — "*Bearings and Bearing Alloys*," by P. T. Holligan—Liverpool Engineering Society, The Temple, Dale Street, Liverpool, 7.0 P.M.

10th Dec.—IRON AND STEEL ENGINEERS GROUP—Twenty-Fourth Meeting—Discussion on Blast-Furnace Practice—4 Grosvenor Gardens, London, S.W.1, 10.30 A.M.

11th Dec.—NORTH EAST METALLURGICAL SOCIETY—"*Steels and Other Alloys for High-Temperature Applications*," by J. M. Robertson—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 7.15 P.M.

15th Dec.—SHEFFIELD METALLURGICAL ASSOCIATION (Methods of Analysis Group)—"*Analysis of Magnesium Alloys*," by A. Mayer—B.I.S.R.A., Hoyle Street, Sheffield, 7.0 P.M.

17th Dec.—STAFFORDSHIRE IRON AND STEEL INSTITUTE—"*Metallurgical Problems in Stratospheric Flight*," by P. L. Teed—Star and Garter Hotel, Wolverhampton, 7.30 P.M.

18th Dec.—INSTITUTE OF TRANSPORT—"*Transport and the Iron and Steel Industry*," by W. V. Golding—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 7.0 P.M.

18th Dec.—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—Open-Hearth Forum—39 Elmbank Crescent, Glasgow, 6.45 P.M.

TRANSLATION SERVICE

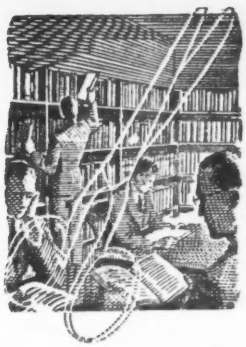
(The previous announcement was made in the November, 1953, issue of the *Journal*, p. 326)

TRANSLATION AVAILABLE

No. 478 (Russian). O. A. ESIN and A. I. OKUNEV: "The Kinetics of the Interaction of Metal and Slag from the Point of View of the Ionic Theory." (*Izvestiya Akademii Nauk SSSR, Otdelenie Tekhnicheskikh Nauk*, 1952, No. 10, pp. 1472–1482).

CHARGES FOR COPIES OF TRANSLATIONS.—The charge for translations is £1 for the first copy and 10*s.* for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

ABSTRACTS AND BOOK NOTICES



IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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ORES—MINING AND TREATMENT

Despite Good Prices . . . Interest Lags in Philippine Manganese. W. F. Boericke and N. N. Lim. (*Eng. Min. J.*, 1953, **154,** Mar., 97–99). A brief survey is given of the Philippine manganese ore industry since 1937. Despite higher relative values, post-war production has declined, mainly as a result of high labour costs, import controls on equipment, and unsettled local conditions.—K. E. J.

Bethlehem's Marmora Mine Prepares for Production. (*Eng. Min. J.*, 1953, **154,** Apr., 95–97). The existence of a blind magnetite orebody at Marmora, Ontario, was revealed in 1949 by aero-magnetic survey, and stripping for open-pit production is now being done by Bethlehem Mines Corp. The concentration, to produce some 500,000 tons of concentrate (60–65% Fe), will be completed in 1954. Present points of interest are new rotary-drilling blasting techniques, and good traffic and equipment handling arrangements.—K. E. J.

The Agglomeration of Ore Fines and Dusts by Sintering. G. Müller. (*Met. u. Giesserei Techn.*, 1952, **2,** Aug., 263–268). The GHH, AIB, and Lurgi sintering processes are described.

Large Ore Carriers for Great Lakes Service. (*Engineer*, 1953, **196,** Aug. 7, 170–172). Three new iron ore steamers of about 18,400 tons deadweight for service on the Great Lakes are described.—R. A. R.

Concentrate Stocking a Help in Shipping Lake Iron Ores. J. J. Foucault. (*Eng. Min. J.*, 1953, **154,** Mar., 79–80). Stockpiling of Mesabi concentrates enables full use to be made of the Lake shipping season, and reduces dislocations caused by weather conditions. Partial bedding is an added advantage. Details are given of the plant at the Holman-Cliffs mine of the Mesaba-Cliffs Mining Co. : a rate of 600 tons/hr. is reached with a link-belt stacker (boom radius 115 ft.) and trailing conveyor, building two piles 550 ft. long, 125 ft. wide, and 42 ft. high.—K. E. J.

Steep Rock's "A" and "B" Zones to Yield 3½-Million Tons per Year. K. L. McRorie. (*Eng. Min. J.*, 1953, **154,** Apr., 82–85). Details are given of plans and developments for increasing output of iron ore from the deposits at the site of Steep Rock Lake. The first underground mine at Errington ("B") zone is being developed ; there will be three levels, the lowest for drainage, and output planned is 1½ million tons/year. Silt is being removed at Hogarth ("A") zone to enable open-pit work to commence. Production should reach 2 million tons/year in 1955.—K. E. J.

Pilot Cyclone Plant Paves Way for Two Full-Scale Operations. W. R. Van Slyke and R. A. Derby. (*Eng. Min. J.*, 1953, **154,** Apr., 88–94). Details are given of experience with a 50 ton/hr. Dutch State Mines cyclone separator treating $-\frac{3}{16}$ in. +65 mesh Mesabi ore at the Holman-Cliffs mine. Difficulties included balance and preparation of feed, medium loss, build-up of tramp material, feed control, and water availability. Full-size plants are being commissioned.—K. E. J.

The Reduction-Oxidation Process for the Treatment of Taconites. F. M. Stephens, jun., B. Langston, and A. C. Richardson. (*J. Met.*, 1953, **5,** June, 780–785). The authors describe a new process for the treatment of oxidized taconite ores, combining a low-temperature gaseous-reduction step and a highly exothermic controlled re-oxidation step to give a process which requires no external heat. The high iron recovery and the greater ease of grinding the processed ore indicate that the method will be economically attractive.

Measurement of Air Flow Through the Strand in Sinter Plants. F. Jordan and M. P. Newby. (*J. Iron Steel Inst.*, 1953, **175,** Dec., 360). [This issue].

Thermal Beneficiation of Low Grade Manganese Ores. P. K. Gupte, G. P. Contractor, and B. R. Nijhawan. (*J. Sci. Indust. Res.*, 1953, **12,** May, 230–233). The reactions involved in beneficiation of low-grade manganese ores are indicated and experiments showing the value of silica or sillimanite furnace linings are detailed. A product suitable for good quality ferromanganese manufacture is obtained.

FUEL—PREPARATION, PROPERTIES, AND USES

Some Effects of Moisture on the Combustion of Coal. G. Whittingham. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1953, **17,** June, 229–236). This review of the literature shows that combustion pot measurements on beds of the chain grate type, in conjunction with plant experience, have provided quantitative data showing what the use of water may achieve in relation to improved efficiency and reduced idle time. (31 references).—R. A. R.

Production and Use of Energy : Industrial Consumption of Electricity. (*Iron Coal Trades Rev.*, 1953, **166,** June 19, 1408–1410). Summaries are given of papers presented to the fifth British Electrical Power Convention. The subjects include utilization of fuel, the future level of coal consumption, district heating schemes and heat for industry, and the relation of electricity to national prosperity.—G. F.

Heat Transfer in the Furnaces of Water-Tube Boilers. G. G. Thurlow. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1953, **17,** May, 173–199). The literature is reviewed. (74 references).—R. A. R.

Tubular Air-Heater Problems. E. F. Rothemich and G. Parmakian. (*Trans. Amer. Soc. Mech. Eng.*, 1953, **75,** July, 723–728). The paper discusses deposits in air heaters, their effect on performance, maintenance and design.—D. H.

Air-Preheater Design as Affected by Fuel Characteristics. H. Karlsson and W. E. Hammond. (*Trans. Amer. Soc. Mech. Eng.*, 1953, **75,** July, 711–722). The authors discuss the factors affecting the design of air preheaters for power station boilers, with special reference to corrosion by flue gases from inferior fuels.—D. H.

Experiments on the Sampling of Coal: An Account of Recent Work Carried Out for the British Standards Institution. E. H. M. Badger. (*J. Inst. Fuel.*, 1953, **26,** July, 17–32).

The Total Mineral Matter in Coal and Its Influence upon Coal Classification. D. Flint. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1953, **17,** Apr., 133–142). The literature is reviewed. (58 references).—R. A. R.

Effects of Reactivity and Some Other Variables on Gasification of Coke with Steam. L. J. Jolley and A. Poll. (*J. Inst. Fuel*, 1953, **26,** July, 33–44). An examination of the literature is made, and some experiments described. Results of particular interest concern rate of supply of steam, effect of particle size, and reactivity during gasification. It is concluded that no simple and reliable method of measuring the true reactivity of coke to steam is yet available and a single practical assay is unlikely to be developed.—D. L. C. P.

Problems in the Disposal of Phenol Waste in Coke Plants. G. E. Muns and C. V. Thompson. (*Amer. Iron Steel Inst.: Blast Furn. Steel Plant*, 1953, **41,** July 761–769). The sources of phenol in the waste liquor of coke-oven plants are reviewed and methods of extraction are described. These include extraction with a liquid, such as benzol, and subsequent washing with caustic soda. Hot vapour extraction followed by washing with caustic soda and biological oxidation are also described. Methods of analysis for phenols in water are reviewed.—B. G. B.

Reactivity of Coke to Sulphur Trioxide. R. W. Kear and G. Whittingham. (*Fuel*, 1953, **32,** July, 265–278). An apparatus and technique have been developed for determining the reactivity to sulphur trioxide of cokes prepared from coals of different rank. The cokes were prepared by carbonization at 600° and 960° C. and the reactivity was determined over the temperature range 100–500° C. For all the cokes the extent of sulphur trioxide reduction increases with temperature in a complex manner, although cokes derived from low-rank coals are the most reactive. The mechanism of the reaction between coke and sulphur trioxide is discussed briefly.—B. G. B.

New Gas-Producer Plant in South Africa: Wellman-Galusha Plant Serves Vereeniging Furnaces. (*Iron Coal Trades Rev.*, 1953, **167,** July 10, 87–88). A new gas-producer plant, consisting of seven 10-ft. dia. Wellman-Galusha machines, is nearing completion at the Klip works of Union Steel Corp. (of South Africa) Ltd. The fuel-handling, hot-gas, and gas-cleaning plants are described, and the instrumentation is outlined.—G. F.

The Science and Art of Electro-Precipitation. D. O. Heinrich. (*Eng. Boiler House Rev.*, 1953, **68,** June, 179–185). An analysis of factors governing the behaviour of dusts subjected to corona discharge is made, and the art of applying the scientific technique to industrial precipitators is considered. Experience is necessary to allow for re-entrainment, and the resistance of the collected dust layer. It is considered that resistivity must be a relevant factor in formulating guarantees of operating efficiency.—D. L. C. P.

Notes on Heating Metallurgical Furnaces with Oil Fuel. G. Cain. (*Mét. Constr. Mécan.*, 1953, **85,** June, 495, 505). A brief account of the use of oil fuel for heating metallurgical furnaces is given. A reduction in the amount of oil fuel used and also in the amount of attention required can be obtained by fitting automatic temperature control.—B. G. B.

TEMPERATURE MEASUREMENT AND CONTROL

An Instrument for the Direct Measurement of Intense Thermal Radiation. R. Gardon. (*Rev. Sci. Instruments*, 1953, **24,** May, 366–370). The instrument described is designed for the measurement of the intensity of thermal radiation in the range of 1 to 100 cal./sq. cm./sec. It consists of a thin circular foil of blackened constantan, soldered round its circumference to a massive copper block. Energy absorbed by the foil causes a radial heat flow to the copper, the temperature of the centre of the foil rising above that of the circumference. A copper wire is attached to the centre of the foil, and a thermocouple is formed, from which the intensity of the radiation can be measured in terms of the temperature difference across the foil.—L. D. H.

Electronics in Temperature Control. D. K. Das Gupta and R. J. Russell-Bates. (*Instrument Practice*, 1953, **7,** June, 596–608). After outlining the development of methods of temperature measurements, the authors discuss the principles of automatic temperature control. Some representative types of modern control equipment are then described in greater detail, with reference to the principles already outlined. The use of servo-mechanisms is discussed. (51 references).

A Special Thermocouple for Measuring Transient Temperatures. D Bendersky. (*Mech. Eng.*, 1953, **75,** Feb., 117–121).

The Tungsten/Molybdenum Thermocouple for Immersion Pyrometry. J. P. Simons, C. G. Hamstead, and E. J. Burton. (*J. Iron Steel Inst.*, 1953, **175,** Dec., 402–407). [This issue].

Methods and Instruments for Measuring Temperatures and the Use of 'Thermistors' As a New Possibility for This Purpose. A. S. Vos. (*Chemisch Weekblad*, 1953, **49,** Jan. 31, 68–76). [In Dutch]. Difficulties arising in the use of thermocouples and platinum resistance temperature measuring devices are discussed with special reference to : (*a*) measurement of rapidly fluctuating temperatures ; and (*b*) their suitability for use in a confined sealed space designed to prevent either the addition or the removal of heat.—R. A. R.

A Low Temperature Bath for Constant Temperature Studies. J. Vajda and D. P. Hart. (*Rev. Sci. Instruments*, 1953, **24,** May, 354–355). A bath is described for maintaining steel impact specimens at constant temperatures ranging from −16° to −196° C. The bath, a copper container insulated by polystyrene (Styrofoam), is refrigerated by a controlled input of liquid nitrogen. To maintain a pre-determined temperature, a furnace controller is operated by a solenoid valve, which controls the input of nitrogen. The temperature of the specimen is measured by a thermocouple embedded in a dummy specimen in the bath.—L. D. H.

A High Temperature Thermoregulator. F. Rosebury. (*Rev. Sci. Instruments*, 1953, **24,** May, 398–399). The range of this instrument is from 500° to 1100° C. A platinum wire resistance element forms an arm of a bridge circuit ; an increase in resistance of the element due to a rise in temperature varies the anode current of a thyratron tube, operating a relay which opens the heater power circuit. For lower temperature ranges, nickel could be substituted for the platinum element.—L. D. H.

REFRACTORY MATERIALS

Castable Refractories in the Steel Mill. J. D. McCullough. (*Iron Steel Eng.*, 1953, **30,** June, 84–89). This paper discusses castable refractories with an alumina–silica base and densities of the order of 125 lb./cu. ft. Their properties are briefly examined, including their thermal conductivity, and typical applications are given.—M. D. J. B.

High Temperature Silicate Chemistry Investigations by C.S.I.R.O. E. R. Segnit and J. D. Wolfe. (*Chem. Eng. Min. Rev.*, 1953, **45,** Mar. 10, 215–219). A description is given of the equipment and methods used in the Cement and Ceramics Laboratory, Fishermen's Bend, Victoria, Australia, for heating to high temperatures and quenching refractory mixtures in order to obtain data for equilibrium diagrams. The wiring diagram of the platinum furnace temperature controller which holds the temperature within ± 0·5° C. is given.—R. A. R.

A High-Temperature Laboratory Catenary Kiln. G. Economos and F. E. Vinal. (*J. Amer. Ceram. Soc.*, 1953, **36,** June, 204–206). The catenary curve ($y = a \cosh x/a$) was analysed to find the dimension of a self-supporting arch for kiln construction. A height-to-base ratio of 1 : 1 was found to be advisable. Detailed construction data are given for a kiln with a 0·5-cu. ft. chamber. A parallel heating element with a low-voltage high-current circuit is described.—E. C. S.

Sonic Analysis for Solid Bodies. N. N. Ault and H. F. G. Ueltz. (*J. Amer. Ceram. Soc.*, 1953, **36,** June, 199–203). Sonic frequencies of ceramic materials made into bar specimens were determined at various temperatures, and modulus of elasticity values were then calculated. Using the method of 'sonic analysis', crystalline inversions may readily be detected, and their effect on the modulus of elasticity determined. Other effects are observed, including a decrease in

Young's modulus on heating single-phase bodies, and the effects produced by differential thermal expansion in multi-phase bodies. The bodies studied included Al_2O_3 ; MgO. Al_2O_3 ; MgO ; and ZrO_2.—E. C. S.

Electrical Conductivity of Some Commercial Refractories in the Temperature Range 600° to 1500° C. V. E. J. Chiochetti and E. C. Henry. (*J. Amer. Ceram. Soc.*, 1953, **36,** June, 180–184). The electrical resistance of commercial refractories was measured in the range 600–1500° C. Log of resistivity was plotted against the reciprocal of the absolute temperature. Fireclay, high alumina, mullite-type, and fused-cast alumina brick containing chromite, gave straight lines. Silica and fused-cast alumina brick showed slight deviations. Fused-cast alumina brick containing both α- and β-Al_2O_3 and basic brick exhibited a different type of curve.—E. C. S.

Zebra Roofs. F. Procháska. (*Hutnik*, (Prague), 1953, **3,** 4, 79–82). [In Czech]. A survey and analysis of zebra-roof practice are given. Properties of the various refractories used are considered, and their application in zebra roofs is discussed.—P. F.

Super Refractories. R. H. Warring. (*Machinery Lloyd*, 1953, **25,** May 2, 53, 55). The uses of bonded silicon carbide and bonded fused aluminium oxide are discussed. As they are strongly resistant to corrosion and abrasion, have a high hot strength, and are chemically inert, they have been successfully employed as liners in rocket motors, skid rails at the charging end of a reheating furnace, and as guides supporting newly drawn steel wire as it passes through pickling and plating tanks.—L. J. L.

Indian Chrome Ores—Their Characteristics and Use as Refractories. J. C. Banerjee. (*J. Sci. Indust. Res.*, 1953, **12,** May, 224–229). Grade I ores (over 46% Cr_2O_3) are not common in India and are conserved for metallurgical use. Many ores in the 30–46% Cr_2O_3 range can be selected for the manufacture of refractories, particularly if a high proportion of MgO is used. The specifications for chrome ore may require modification to emphasize the required characteristics for this purpose.—J. O. L.

Metallurgical Applications of Magnesite Bricks. A. Bosment. (*Mét. Constr. Mécan.*, 1953, **85,** July, 563–564). The major defect of pure magnesite bricks is their low resistance to thermal shock. The uses of bricks made of magnesia with chromium oxide (chrome-magnesite) are described ; these include linings for open-hearth and electric furnaces. The use of steel-clad chrome-magnesite bricks is considered briefly, together with the ' zebra ' type of construction with alternate silica and chrome-magnesite bricks.—B. G. B.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Further Studies of the Tuyere Zone of the Blast Furnace. J. B. Wagstaff. (*Trans. Amer. Inst. Min. Met. Eng.*, 1953, **197;** *J. Met.*, 1953, **5,** July, 895–902). The author has made a quantitative study of the ' raceway ' existing in front of the blast-furnace tuyere and correlated its size with the penetration of the blast. From evidence on the height and width of the raceways, it is suggested that they overlap. The size of the coke in this zone during normal operation has been measured photographically and found to vary appreciably with time.—G. F.

Belt-Charged Blast-Furnaces of S.A. John Cockerill, Belgium. G. Hookham. (*J. Iron Steel Inst.*, 1953, **175,** Dec., 409–419). [This issue].

Blast Furnace Charged with Belt Conveyors at the Société John Cockerill Works in Seraing. L. Halbrecq. (*Blast Furn. Steel Plant*, 1953, **41,** July, 743–750). Owing to congestion around the blast-furnace plant and the distance of the bins from the furnaces, the ore and coke are transported to the furnace tops by means of indiarubber belt conveyors. Three furnaces are charged by this method. The main conveyor belt from the bins can charge independently any one of these three furnaces. One main control room controls automatically the charging of all three furnaces. Details of the control system are given. The plant has operated very satisfactorily for over three years.—B. G. B.

Water-Cooling of Blast Furnaces: Considerations of Design, Installation, and Maintenance. R. Kingston. (*Iron Coal Trades Rev.*, 1953, **166,** June 19, 1395–1397). The author describes the different types of water-cooling systems used in modern blast-furnace operation, and discusses heat losses in relation to the water-flow required. The problem of water purity, an important controlling factor, is also considered.

Lorain Cuts Banked Blast Furnace Blowing-In Time from 72 to 30 Hours. W. W. Durfee. (*J. Met.*, 1953, **5,** June, 791–793). The author outlines the method adopted by the Lorain Works of United States Steel Co. for returning banked blast-furnaces to blast. In this method the taphole is, in effect, converted into a tuyere, and the time for returning a furnace to 80% normal blast has been reduced from about 72 to 30 hr.—G. F.

A Flue Dust Recovery Plant for Blast-Furnaces. (*Engineer*, 1953, **195,** June 5, 810–811). A description is given of a new blast-furnace flue dust recovery plant installed at Jones and Laughlin Steel Corp., Aliquippa Works. The plant is designed to handle a flow of 16,000 gal./min. of washer water containing approximately 100 grains of flue dust per gallon, with an iron content of about 45% on a dry basis. Once removed from the water, the dust is thickened to a 50% solids concentration.—M. D. J. B.

Permeability of Blast-Furnaces Burdens. P. B. Stubbs and R. L. Stephenson. (Eastern States Blast Furnace and Coke Assoc.: *Blast Furn. Steel Plant*, 1953, **41,** July, 772–775). The results of an investigation into the permeability of various materials used in the blast-furnace are given. The materials were contained in a model 2 ft. in dia. and 3 ft. high. The permeability of a bed of coke was found to agree with that calculated from theory, but the permeability of complex burdens did not agree with the theoretical value. Coke finer than 1 in. severely reduced the permeability of the burden. With 10% coke less than 1 in., the permeability increased by 45%. Sized ore and agglomerated material improved the permeability of the burden.—B. G. B.

PRODUCTION OF STEEL

25 Years of Progress. H. R. Fraser. (*ISCOR News*, 1953, **18,** July, 10–21, 54–58). This article is the story of the growth of the three plants of the South African Iron and Steel Corp., Ltd., at Pretoria, Thabazimbi, and Vanderbijl Park, during the last 25 years. It is chiefly concerned with the economic development.—J. C. B.

Pittsburgh Steel Company Increases Production Capacity. (*Iron Steel Eng.*, 1953, **30,** June, 126–130). This article describes briefly the expansion of the steel plant division of The Pittsburgh Steel Co., whose annual production has gone up from 1,072,000 to 1,560,000 tons. The 12 open-hearth furnaces have been increased in capacity from 150 to 250 tons each. New larger ladles, three new 300-ton cranes, and six new soaking pits have been installed.—M. D. J. B.

Flow Patterns in Furnaces. J. H. Chesters. (*Soc. Chem. Ind.* (*Chem. Eng. Group*), 1950, **32,** 65–73). A summary of the results obtained with two-dimensional models reported earlier is given (*see J. Iron Steel Inst.*, 1949, **162,** Aug., 385 *et seq.*), and is followed by the results obtained in three-dimensional models. These are applied to $\frac{1}{24}$th and $\frac{1}{12}$th scale models of both Maerz and Venturi type furnaces. To follow the flow paths, spherical aluminium dust was injected into the fluid medium. Work with hot models had been started and the results are in good agreement with the cold fluid ones. The difficulty of finding a suitable tracer for use at the high temperatures in actual furnaces is discussed.—J. C. B.

Heating-Up Open-Hearth Furnaces After Rebuilding. H. M. Kraner and C. N. Jewart. (*Indust. Heating*, 1953, **20,** Mar., 547–554 ; May, 959–968). Silica bricks are sensitive to heat shock, but only in the lower temperature ranges ; thus, it is not necessary to heat up rebuilt open-hearth furnaces very slowly as believed previously. On the basis of tests, it has been determined that a rate of 140° F./hr. is safe in the critical 100–600° F. range, after which faster rates can be applied. Methods of heating up while rebuilding are considered in detail. Special heat-up assembly developed to permit the proper heating rate to be used is discussed, and a survey of heating-up times in the industry is presented. Data from 92 plants comprising 706 furnaces are incorporated in this survey.—B. G. B.

Open Hearth Screw Steels Replacing Bessemer. S. Feigenbaum. (*J. Met.*, 1953, **5,** June, 796). The author outlines the practice adopted at the Pittsburgh Works of Jones and

Laughlin Steel Corp. for the production of free-cutting steel in the basic open-hearth furnace. Experience indicates that in ultimate use these steels are superior to the acid Bessemer grades which they have displaced.—G. F.

Open Hearth Slag Removed Economically by Blasting. J. O. Dague. (*J. Met.*, 1953, **5**, July, 881–883). The author outlines various methods tried out at the Lackawanna plant of Bethlehem Steel Co. for removing slag from open-hearth slag pockets, and gives details of the blasting procedure finally adopted. Compared with other methods, blasting is cheaper, saves time, has greater availability, and allows higher production.—G. F.

Monolithic Linings in Furnace Spouts: 1. Working Conditions Improved at Armco Steel Corp. V. W. Jones. **2. Monolithic Linings Successful at Crucible Steel Co.** G. M. Burrier. **3. Practice Adopted at Bethlehem Steel Co.** J. C. MacNeill. (*J. Met.*, 1953, **5**, July, 877–880). The methods adopted in making monolithic spouts for furnaces at three American works are outlined. The advantages include easier removal of skulls, easier lining, less maintenance, and longer spout life.

Steam Jets Efficiently Remove Dust from Open-Hearth Furnace Flues. J. Peterson. (*J. Met.*, 1953, **5**, June, 794–795). The open-hearth furnaces at the Midland Works of Crucible Steel Co. are fitted with steam jets in the regenerator flues and in the clean-out tunnel running the width of the checker chambers. The system is successful in preventing build-up of dust, thus preventing delays and maintaining checker efficiency.—G. F.

The Effect of the Techniques of Smelting and Casting on the Quality of Steel. N. N. Dobrochotow. (*Foundry Practice* (Moscow), 1952, No. 7, 2-6 : *Met. u. Giesserei Techn.*, 1953, **3**, May, 163–168). Open-hearth furnace practice in the U.S.S.R. is reviewed. High tapping temperatures are advocated. To prevent defects in steel caused by tapping at very high temperatures : (1) The hydrogen content should be kept low ; (2) the steel bath should have a thick layer of slag ; (3) it should be deoxidized in the ladle ; and (4) rather large amounts of aluminium should be added.—R. A. R.

Vancouver Steel Co., Ltd., Uses Mullite Roofs on Electric Furnaces. G. R. Heffernan. (*J. Met.*, 1953, **5**, July, 884–885). At the Vancouver Steel Co. Ltd., mullite roofs are now used in the 4000-kVA, 11-ft. dia. swing-roof electric furnace and give an average life of 322 heats. The cost is about 1¾ times that of the replaced silica roofs, which averaged 112 heats. Other advantages of the mullite roof are outlined.—G. F.

Note on the Nature of Conduction in Liquid Iron Oxide and Iron Silicates. M. T. Simnad and G. Derge. (*J. Chem. Phys.*, 1953, **21**, May, 933–934). By measurement of current efficiency for the entire range of melts of iron oxide and silica-saturated slag it has been shown that all compositions show some ionic conductivity, increasing with silica concentration. This corresponds with theoretical considerations.—J. O. L.

Activities of Constituents of Iron and Steelmaking Slags. Part II—Manganous Oxide. E. T. Turkdogan and J. Pearson. (*J. Iron Steel Inst.*, 1953, **175**, Dec., 393–398). [This issue].

Activities of Constituents of Iron and Steelmaking Slags. Part III—Phosphorus Pentoxide. E. T. Turkdogan and J. Pearson. (*J. Iron Steel Inst.*, 1953, **175**, Dec., 398–401). [This issue].

Segregation: Major Cause of Flakes in Alloy Gun Steels. J. B. Gero and A. R. Troiano. (*Iron Age*, 1953, **171**, Mar. 26, 133–137). Blooms and forgings of SAE 4340 Cr–Ni–Mo steel containing 0·08% V were examined to discover the cause of flaking. The following conclusions are reached : (1) Flaking in these large sections is the direct result of dendritic segregation. (2) Alloying elements that show the greatest tendency to segregate are those that have the greatest effect in retarding transformations in the pearlite range. (3) Heat-treating cycles must take into account the long transformation times required for the points of highest segregation. Dendritic segregation is considered to be a natural physical phenomenon and can only be lessened by more rapid solidification. (22 references).—A. M. F.

The Flame Treatment of Billets in an Experimental Plant. J. Cincarek. (*Met. u. Giesserei Techn.*, 1953, **3**, May, 168–172). The technique of deseaming billets with the oxy-acetylene flame is described.—R. A. R.

FOUNDRY PRACTICE

Science, Technology and Craftmanship. E. Longden. (Institute of British Foundrymen : *Foundry Trade J.*, 1953, **94**, June 18, 691–694). The author discusses the interrelation of science, technology, and craftmanship in the foundry industry and suggests that a parent research organization for all cast metals should be established.—B. C. W.

Iron and Steel. J. F. B. Jackson and G. R. Woodward. (*Reports on the Progress of Applied Chemistry*, 1952, **37**, 297–315). Improvements and developments in steel casting technique during 1952, and research in progress, are reviewed by the first author, whilst the second author reviews work on iron castings. (19 and 48 references, respectively).—R. A. R.

Castings—A Material for Ammunition. F. E. Shumann. (*Foundry*, 1953, **81**, July, 88–93). This is a discussion of the possibilities and difficulties in the production of shell cases and shell components by casting instead of by forging or machining. Examples are given of the successful production of 60, 81, and 280 mm. casings, and of several components.

Designing an Ideal Sand Casting. T. H. Trevithick. (*Product Eng.*, 1953, **24**, Feb., 168–170). The author reviews those factors that make a casting ideal from a production as well as a function viewpoint. The requirements of an ideal casting are to permit liberal pattern draft, minimize surface projections, solidify progressively, and to have liberal fillet radii and minimum re-entrant angles. Suggested practices are supported by sketches.—A. M. F.

The Characteristics of Cupolas. (*J. d'Informations Techniques des Industries de la Fonderie.*, 1952, Oct., Supplement, I–VIII). Data concerning the dimensions and performance of cupolas are presented in tabular form, together with a number of equations for the calculation of furnace characteristics.—B. G. B.

Balanced Blast—Cupola Boosts Iron/Coke Ratio—Offers Other Advantages. N. Bennett. (*Canad. Metals*, 1952, **15**, Oct., 56–58). The balanced blast is obtained by using four rows of tuyeres. The lowest row has three kindling tuyeres, the next seven main tuyeres, and two top rows have seven auxiliary tuyeres. It is claimed that the balanced blast technique increases the iron-coke charge ratio, gives uniformity of operation and ease of control, and a small saving in the cost of the iron produced.—J. C. B.

Cupola Operation *vs* Charge Distribution. W. E. Kinread and W. A. Farnell. (*Canad. Metals*, 1952, **15**, Oct., 66). This short note shows the importance of charging a cupola evenly over its cross-section to attain the maximum working temperatures and highest metal/coke ratios.—J. C. B.

How to Bott the Cupola Tap Hole. P. Dwyer. (*Foundry*, 1953, **81**, July, 163, 166). The author briefly discusses the operation of the cupola in respect to the opening and closing of the taphole. Details are given of the procedure for closing the taphole.—B. C. W.

Hot-Metal Receivers for Iron Foundries. (*Engineering*, 1953, **176**, July 3, 27). **Hot Metal Receivers.** (*Indust. Gas*, 1953, **16**, June, 259–262). *See J. Iron Steel Inst.*, 1953, **175**, Sept., 82.—M. D. J. B.

Rolling of Thin Sheet from Molten Cupola Iron. V. Gudrych. (*Metallurgie u. Giessereitechnik*, 1952, **2**, Nov., 412). A Russian process of rolling cast iron is described in very general terms. It is used in conjunction with a cupola having a fore-hearth. From 10 to 20 cwt. of sheets can be produced per hour from 0·02 to 0·05 in. thick, 20 in. wide, and 3 ft. 3 in. long.—R. A. R.

Melting Iron in the Reverberatory Furnace. J. G. Wingett and H. E. Simmons. (*Amer. Foundryman*, 1953, **23**, May, 94–99). The use of small reverberatory furnaces for the batch melting of a range of irons is discussed with particular reference to the method of firing and the performance and maintenance of the refractory lining. The problem of obtaining high melting temperatures without undue oxidation is considered. The authors conclude that a combination of oil and natural gas firing yields the best results.—B. C. W.

How to Eliminate Some Machining on Castings. H. L. Smith. (*Foundry*, 1953, **81**, June, 215, 217, 220). By the use of hinge tubes and screw shells in moulding, the subsequent machining of holes or screw threads may be avoided. Tin forms can be used to produce lugs, bosses, or feet without the necessity for complicated cores.—B. C. W.

Low-Frequency Induction Melting Employed in Malleable Foundry. C. Pollock. (*Foundry*, 1953, **81**, July, 108–111,

226–269). A description is given of the use of single-phase 525–550 V. low-frequency Ajax-Wyatt 350–400-kW. furnaces for melting iron of average composition C 2·3% and Si 1·2%, used in the production of malleable iron castings. The average rate of melting is 1200 lb./hr. A detailed account is given of the charging, melting procedure, maintenance, and relining of the furnaces which are operated continuously.

Castings for the Smithy and Forge. W. S. Spenceley. (Inst. British Foundryman : *Foundry Trade J.*, 1953, **94,** Apr. 23, 467–473 ; Apr. 30, 503–506). A description is given of some castings for power hammers and friction drop-hammers, as well as their mode of functioning and the requirements demanded of such plant. Methods of running and risering are discussed and chilling or heat absorption methods are contrasted with pressure feeding. Core production and the co-ordination of venting methods lead to consideration of the degree of skill required in craftsmen selected for such work.—L. E. W.

Economical Use of Metals in the Foundry. D. W. Hammond. (Inst. British Foundrymen : *Foundry Trade J.*, 1953, **94,** Apr. 16, 433–438 ; Apr. 23, 475–479). The author examines methods for the better utilization of raw materials in the foundry, in particular, the conversion of swarf and borings into useful metal. Cupola, rotary furnace, and arc melting are discussed in some detail and the basic principles and economics of the Croft process introduced. Remelting cast iron swarf by : (1) Briquetting and cupola melting ; (2) cannistering and cupola melting ; (3) electric furnace melting ; and (4) rotary furnace melting, is surveyed. Feed machine design is dealt with.—L. E. W.

" Foundry " Development in the Textile Industry. B. Gale. (*Inst. Brit. Foundrymen*, June 16–19, 1953, *Advance Copy No.* 1066). A description is given of the methods used by the subsidiary companies of the Textile Machinery Makers Ltd. in the production of a wide range of castings for textile machinery. The arc melting of swarf is described—B. C. W.

Growth Characteristics of Ingot-Mould Irons in Air and Vacuum. J. W. Grant. (*Inst. Brit. Foundrymen*, June 16–19, 1953, *Advance Copy No.* 1063). Theories explaining the growth of cast iron are reviewed and discussed. Using mainly an ingot-mould iron, experiments were carried out to study the oxidation products formed at sub-critical temperatures, the growth on repeated heating in air and vacuum, and the effect of oxidation on the formation and transformation of austenite. Appreciable growth occurred in a vacuum and in pure dry argon ; although growth also occurred in oxidizing atmospheres, a pre-anneal in air inhibited subsequent growth in vacuum. Growth is primarily due to the expansions and contractions resulting from the solution and reprecipitation of graphite, and also from the $\alpha \rightleftharpoons \gamma$ transformation. In an oxidizing atmosphere the oxidation of silicon, iron and manganese will also cause growth. The inhibiting effect of oxidation on the growth in vacuum is explained by the formation of a protective envelope round the graphite flakes which prevents their solution and reprecipitation.—B. C. W.

" Liquid " Inoculation. M. M. Turbovskii. (*Przeglad Odlewnictwa*, 1953, **3,** 2, 59–62 ; translated from *Liteinoe Proizvodstvo*, 1952, No. 6, 16). [In Polish]. Liquid inoculation consists of adding the modifying agent in a liquid state. The liquid inoculation of white iron (2·8–3·1% C and 0·7–1·2% Si) with 25% of grey iron (3·2–3·5% C and 2·0–2·4% Si) to produce grey iron is described. For comparison, normal inoculations with 0·1% Al and 0·7% of 45% ferrosilicon were made. The chemical compositions of the initial materials and end products as well as their structure and mechanical properties are given.—V. G.

The Contribution of Primary Crystallization in Nodular Cast Iron. H. Gries and U. Maushake. (*Giesserei Technisch-Wissenschaftliche Beihefte*, 1952, Mar., 493–502). The literature is critically reviewed from the points of view of (*a*) nuclei, (*b*) crystal structure, and (*c*) the crystallization process. The question as to whether the spherolithic form comes from the molten or from the solid state is discussed. A comprehensive microscopical investigation is described which clearly shows a series of different phenomena in which the author's results differ from previous work. Primary crystallization in silicon-killed melts was especially marked. The dendritic structure was investigated. The experimental results are compared with known theories and the possibility of a double crystallization mechanism is discussed.—R. J. W.

Malleable Iron Castings. J. H. Lansing. (*Foundry*, 1953, **81,** May, 141–145). The author surveys research activities on ways to improve and standardize malleable foundry operations.—L. E. W.

Elevator-Type Annealing Furnaces for Blackheart. (*Foundry Trade J.*, 1953, **94,** May 21, 583–584). Details are given of American practice and recent results obtained in the annealing of black-heart malleable cast iron in furnaces of basic design similar to those for the gaseous annealing of white-heart malleable iron.—L. E. W.

Steel Castings. C. W. Briggs. (*Foundry*, 1953, **81,** May, 131–135). Advancements in the technique of steel casting production are reviewed.—R. A. R.

Steel Castings and Their Application. F. Rowe. (*Iron Coal Trades Rev.*, 1953, **166,** May 29, 1243–1244 : *Foundry Trade J.*, 1953, **94,** May 7, 525–527). Some of the difficulties encountered in the production of steel castings are outlined. The mechanical properties of equivalent wrought and cast steels are compared.—G. F.

Developments in Steel Castings in the Heavy Power Plant Industry. F. Buckley. (*Inst. Mech. Eng., Preprint*, 1953, Feb. 27). A brief outline is given of developments in the science of foundry production and practice, and trends in the application of castings within the heavy engineering industry are discussed. Methods of inspection, including magnetic crack detection, X- and gamma radiography, and supersonic examination are described. The choice of material and the fabrication of articles by welding together separate castings are considered. A strong case is presented for specialization and the concentration of allied types of work in relatively few foundries.—P. M. C.

The Choice of an Electric Furnace Melting Process for Intricate Castings. I. R. Krjanin and G. W. Suschko. (*Foundry Practice* (Moscow), 1951, No. 5, 2–6 : *Met. u. Giesserei Techn.*, 1953, 3, Apr., 147–151). Thirty heats were prepared with carbon steel for castings in 3-ton electric arc furnaces, and the data from 270 heats were evaluated, to assess the value of the basic and acid melting processes. The latter consumed 22% less electrical energy ; acid steel contained fewer non-metallic inclusions, and the fluidity of basic steel was 45% less than that of acid steel.—L. J. L.

Shaking Out, Cleaning, Welding, Steel Castings. J. H. Hall. (*Foundry*, 1953, **81,** Feb., 92–96, 251–255 ; Mar., 194–195, 284–290 ; Apr., 96–97, 250–256 ; May, 218–235). The author discusses steel foundry practice and describes the methods and equipment employed. The cleaning of the casting, removal of necked down heads, gates, and padding, and elimination of defects by welding are discussed in detail. The various welding practices are surveyed, the merits, disadvantages and applications being indicated.—L. E. W.

Feeding of Steel Castings at Greater-than-Atmospheric Pressures. C. W. Briggs and H. F. Taylor. (*Inst. Brit. Foundrymen*, June 16–19, 1953, *Advance Copy No.* 1070). Results are presented of experiments in which external gas pressure was applied to blind risers in a number of different castings so as to produce better feeding. No dependable improvement in feeding efficiency was attained with pressure in side-blind or top-blind risers. Low gas pressures were more beneficial than high pressures as they prevented cope defects, whilst the latter produced metal penetration and bulging of the casting. Capsules of zinc pellets in graphite cylinders were also used to produce pressure in blind risers but the results were not dependable. The authors conclude that greater-than-atmospheric pressures are of no practical advantage in the feeding of castings.—B. C. W.

Effects of Mould Resistance on Internal Stress in Sand Castings. R. N. Parkins and A. Cowan. (*Inst. Brit. Foundrymen*, June 16–19, 1953, *Advance Copy. No.* 1062). Results obtained for sand castings of simple pattern show that the hindrance to the contraction of the casting on cooling is governed by the strength of the moulding sand. The plastic deformation produced in the metal depends on both the high-temperature and the room-temperature sand strength as the yielding of the hot sand is opposed by the cold sand away from the casting.—B. C. W.

Effect of Heat on Clays and Its Bearing on the " Life " of Clay Bonds. S. Davison and J. White. (*Inst. Brit. Foundrymen*, June 16–19, 1953, *Advance Copy No.* 1061). The nature of clay minerals is reviewed with reference to the position and bonding of the hydroxyl groups and the ability of the structure

to adsorb moisture. In some clay minerals moisture is adsorbed on the outer surfaces of the particles and between the lattice layers ; this is discussed in respect of the montmorillonites. On heating, the adsorbed moisture is largely lost below 110° C., whereas the chemically combined moisture (*i.e.*, the hydroxyl groups) is retained until about 400° C. The loss of this moisture with time and temperature above 400° C. results in the disintegration of the clay structure, and the material ceases to become plastic with water. The physical and chemical properties of ten different clays were determined together with the dehydration and re-wetting characteristics, and the changes in the properties on heating. A laboratory test to determine the life of the clays is described.—B. C. W.

Pelleted Foundry Pitch. E. B. Davies, T. F. N. Matthews, and G. Smart. (*Inst. Brit. Foundrymen*, June 16–19, 1953, *Advance Copy No.* 1060). Details are given of the use of pelleted pitch (covered by British Patent No. 632,734) in green sand, dry sand and skin-dry moulds, and in the production of cores.—B. C. W.

Use of Pitch in Moulding Sands. O. Carlsson. (*Gjuteriet*, 1953, **43,** Mar., 47–52). [In Swedish]. Tests were made of the comparative advantages of pitch or coal dust for improving casting texture. English pitch and Swedish coal dust were used, with grain sizes of 0·19 and 0·08 and gas contents of 64% and 34% respectively. In green sand work, good surfaces were obtained with 2% pitch, while 5% dust was needed to give the same result. In all cases pitch gave stronger moulds, reduced cracking and reduced ash in the used sand.

Talc as a Material for Preventing Moulding Sands Sticking to the Surface of Castings. I. L. Faitelson. (*Przeglad Odlewnictwa*, 1953, **3,** 2, 62 ; translated from *Liteinoe Proizvodstvo*, 1952, No. 9, 29). [In Polish].

Plastics in the Foundry. J. F. Driver. (*Machinery Lloyd*, 1953, **25,** Feb. 21, 67, 69, 71, 72). The author discusses the function of moulds and cores, the synthetic resins of which they are now made, surface hardening of green sand moulds, the shell moulding process, and the drying of resin-bonded sand cores.—L. J. L.

Cracks or Fissures in Baked Moulds. P. Nicolas. (*Fonderie*, 1953, **85,** Feb., 3313–3316). The causes of cracks in dry sand and loam moulds are considered. The chief reasons for cracking are given as too high clay content ; too much moisture ; forcing the drying, *i.e.*, using a high temperature for a reduced time ; and sudden cooling on removing the mould from the oven.—J. McK.

Some Notes on the Construction and Use of Moulding Boxes. P. Tincolini and A. Catelani. (*Fonderia Ital.*, 1953, **2,** Feb., 308–312). The authors study mould box requirements for different types of castings. The relative merits of aluminium, light pressed steel, and heavy steel boxes are discussed.

Proposed Standards for Moulding Boxes Having Internal Lengths Exceeding 1600 mm. (*Gjuteriet*, 1953, **43,** Apr., 69–75). [In Swedish]. Owing to the great variety of castings made in these boxes it has been found impracticable to concentrate on only one standard type of box. Proposals are therefore made for four standard elements which can be combined to give the box size required. These are box parts with or without bars, box sides, and bar grids. Dimensioned sketches are given.—G. G. K.

The Fireclay Moulding Process for Repetition Work (Patent Applied for). A. Lösche. (*Met. u. Giesserei Techn.*, 1952, **2,** July, 242–244). A description is given of a new moulding box using fireclay of a special composition which it is claimed can be used fifty times.—L. J. L.

Synthetic Moulding Sand. R. Boerger. (*Met. u. Giesserei Techn.*, 1952, **2,** Oct., 347–350). Synthetic moulding sand is described as a type of sand which contains quartz and clay in clearly defined proportions. A hydrometer for the rapid assessment of the moisture in the sand is described and illustrated.—L. J. L.

The Chemical Structure and Properties of Raw Materials for Core Binders. R. Grochalski. (*Met. u. Giesserei Techn.*, 1952, **2,** Aug., 273–279). The author finds that a particular molecular structure is required to render binders self-consolidating and to enable them to adhere to silicate surfaces. The surface of the quartz sand must be completely enveloped ; this requires an intimate mixture of sand and binders. With molecules of fibrous structure, mixing, if carried on too long, can be harmful, because the sharp quartz particles destroy the long molecular chains. Baking temperatures and times can be determined for each new binder.—L. J. L.

Influences of Time and Temperature on the Properties of Mixtures of Core Sands. J. Vazquez White. (*Inst. Hierro Acero*, 1953, **6,** Jan.–Mar., 21–28). [In Spanish]. Numerous tests on mixtures of core sands have shown that, in spite of maintaining constant proportions of the mixture and constant quality, results were sometimes uniform and at other times varied enormously. The author describes measures taken to determine the variables which can affect the results.—R. S.

Cores for Steel, Iron and Bronze Foundries. M. Guédras. (*Mét. Constr. Mécan.*, 1953, **85,** May, 361–367). The preparation of natural and synthetic sands before use as cores in moulds for steel, iron, and bronze castings is described. The composition of a number of sands is discussed.—B. G. B.

Modern Ideas on Core Making. C. S. Johnson and D. T. Kershaw. (*Inst. Australian Found.*, Victorian Div., 1952 Convention, 141–162). The main requirements of a core and the various types of ingredient used to produce these requirements are reviewed, and the fundamentals of good practice in mixing and baking are emphasized. The use of mechanical aids for core production is mentioned with particular reference to repetition work and core blowing. An adequate system of core inspection, together with the jigging of critical repetition cores, is considered essential.—P. M. C.

Runners and Risers. E. Daybell, P. A. Russell, and R. W. Ruddle. (*Foundry Trade J.*, 1953, **94,** May 28, 601–609). The authors broadly review the application of runners and risers in the steel, iron, and non-ferrous foundries. Points of similarity and difference are discussed in terms of liquid and solid contraction, solidification, and mould material characteristics. The factors requiring close control for good results are emphasized.—L. E. W.

The Use of Exothermic Feeders. G. P. Adams. (*Inst. Australian Found.*, Victorian Div., 1952 Convention, 209–213). After explaining the principle of heat generation by the burning of aluminium with iron oxide to supply the necessary oxygen, the author discusses briefly the methods of use, and the advantages and disadvantages of exothermic feeders.

Some Remarks on Blind Risers and in Particular, on Atmospheric Blind Risers. J. Gélain. (*Fonderie*, 1952, **82,** Nov., 3163–3182). A theory for dimensioning risers is presented based on the fact that the solidification times for two pieces of the same metal cast under the same conditions are proportional to $(V/S)^2$ where V is the volume of the casting and S the surface area. Experiments showed that this was approximately true for castings of different geometric shapes. The most advantageous shape for the riser is a cylinder of height equal to the diameter capped by a hemisphere. The size required is that which gives a V/S ratio for the riser 10% greater than that for the casting which it is to feed. A large casting may be considered as divided into parts each fed by its own riser.—J. McK.

The Fundamentals of the Shrinkage of Steel, Risers, and Trumpets. A. Lincke. (*Met. u. Giesserei Techn.*, 1952, **2,** Nov., 400–404). The correct design of risers and their requirements are discussed.—R. A. R.

Tunnel-Type Continuous Core Stove. (*Foundry Trade J.*, 1953, **94,** May 14, 559–560). A brief description is given of the recently-built horizontal stove at the Thornaby-on-Tees steelfoundry of Head, Wrightson and Co. Ltd. This a gas-fired, tunnel-type, continuous unit designed and constructed by John Mathison Ltd. It differs from most horizontal stoves in that the inlet and outlet points are at the same end. Some design features are included with details of the heating system and operating sequence.—L. E. W.

Study of an Electric Core Drying Stove. S. Rydén. (*Gjuteriet*, 1953, **43,** Apr., 61–68). [In Swedish]. An investigation was made of the process of core drying and the effects of variables such as gas velocity, fresh air input, and amount of stock in the stove. A 24-kW. unit was used, measuring 1·8 × 1·4 × 1·6 m., with an air input of 0·65 cu.m./min. Ordinary bentonite binder was applied and core moisture content was 4%. Drying was accelerated when stove content and air input were low. Results are tabulated.—G. G. K.

The Importance of Efficient Venting from Moulds and Cores to Obtain Faultless Castings. A. Lincke. (*Met. u. Giesserei Techn.*, 1953, **3,** Feb., 59–61). Recommendations are made on the positioning of vents in moulds and cores.—L. J. L.

The Mechanisation of Mould Stripping. G. Chauvin. (*Fonderie*, 1953, **85,** Feb., 3295–3306). The use of vibrating stripping machines is described. These are classified according to the method of obtaining the vibration and the mode of operation. Modifications of design to meet the needs of different practices are described.—J. MCK.

Casting a Large Turbine Cylinder. J. Woodman and R. Taylor. (*Inst. Australian Found.*, Victorian Div., 1952 Convention, 215–221). A description is given of the procedure for moulding and casting of the two halves of a large turbine cylinder for the low-pressure end of a 25,000-kW. turbine. The bottom half was approximately 11 ft. × 15 ft. × 5 ft. and weighed 24¾ tons. The top half was 11 ft. × 12 ft. × 4 ft. and weighed 10¼ tons.—P. M. C.

The Production of Nodular Graphite Cast Iron. R. Rodtke. (*Met. u. Giesserei Techn.*, 1952, **2,** Aug., 280–283). Processes using nickel and ferrosilicon for making nodular iron are critically examined, and experiments carried out by the Institut für Giesserei-Technik, Leipzig, are described. In the latter, pure magnesium was continuously fed into a ladle holding about 35 kg. of molten metal through a tube about 3 ft. long and ⅜ in. inside dia. attached to the lower half of the ladle.—L. J. L.

Shell-Moulding Process. D. N. Buttrey. (*Inst. Brit. Foundrymen*, June 16–19, 1953, *Advance Copy No.* 1059). The characteristics, mode of operation, applications, and advantages of the shell-moulding process are reviewed and discussed.

Shell Moulding. M. J. Sargeaunt. (*Machinery Lloyd*, 1953, **25,** May 2, 57, 59, 61, 63). The shell moulding process is described and the position regarding patents on it in Great Britain is examined.—R. A. R.

Survey of the Shell-Moulding Method of Casting Production. B. N. Ames. (*Inst. Brit. Foundrymen*, June 16–19, 1953, *Advance Copy No.* 1058). The methods used in shell-moulding are discussed with particular reference to those employed at the New York Naval Shipyard. Radiographs are given to show the effect on the internal soundness and macrostructure of the back-up material, the shell thickness, the curing time and the base sand. Mechanical tests indicate that shell-moulded castings in both ferrous and non-ferrous alloys can develop properties and internal soundness equal to, or better than, green sand castings.—B. C. W.

Method of Registering, Clamping, Closing-Up and Supporting Shell Moulds. A. S. Beech. (*Machinery*, 1953, **82,** Apr. 24, 784–786). A new method of registering, clamping, closing up, and supporting shell moulds is described and illustrated with an example of a mould box for two small pistons. The author stresses that all shells should be backed up by ramming synthetic moulding sand with the sand rammer.—R. A. R.

Pattern Dies for Investment Casting. S. Lipson and H. Rosenthal. (*Precision Met. Mold.*, 1953, **11,** Mar., 82–97; Apr., 115–116). Brief details are given of the various types of die used in the preparation of investment casting patterns and factors in die design are discussed.—D. H.

Casting Piston Rings Separately. C. Englisch. (*Berghüttenmann. Monatsh.*, 1953, **98,** Jan., 8–12). Metallurgical principles and casting techniques employed in the series production of piston rings by the static mould method, with particular reference to Swedish practice, are discussed.—P. F.

Pressure Die Casting As a Basis for Other Processes in the Mass Production of Components. R. Grunberg. (*Mét. Constr. Mécan.*, 1953, **85,** May, 369–373). The author discusses the advantages of pressure die casting over other methods of large scale manufacture. The limitations and advantages of pressure casting are compared, in tabular form, with those of nine other processes.—B. G. B.

HEATING FURNACES AND SOAKING PITS

Non-Scaling Steel Reheating Furnace: Fuel Gas Burnt in Two or More Stages. (*Iron Coal Trades Rev.*, 1953, **166,** June 19, 1406–1407). A brief description is given of a new process for reheating steel to 1250–1300° C. with oxidation control. The fuel gas is burnt in two or more stages; in the first stage oxygen is used to take up about half the calorific value of the gas, maintaining temperatures up to 1300° C., and in the second stage the products of this combustion are burnt with air in the preheat chamber (600–700° C.). Recuperation is employed to preheat the fuel or oxygen.—G. F.

Increased Production from Gas-Fired Forge Furnaces. (*Indust. Gas*, 1953, **16,** May, 250–252). Details are given of a new gas-fired forge furnace installed at the works of S. M. Jones Co., Toledo, Ohio, for the heating forging of lengths of bar stock. This high-speed furnace incorporates a split side wall heating chamber with gas-fired line burners firing vertically downward into a refractory bed hearth.—D. H.

Billet Heating Furnace Replaced in 16 Days. (*Steel*, 1953, **132,** June 22, 98–100). A new 2-zone billet reheating furnace was erected outside its building, and moved 44 ft. on anti-friction bearings to its permanent location in a skelp mill train. The structure weighed 1200 tons and had a designed output of 80 tons/hr. A description of the operation, the mill, and its working are given.—D. L. C. P.

Soaking-Pit Practice at the Normanby Park Steelworks of John Lysaght Ltd. A. H. Norris. (*J. Iron Steel Inst.*, 1953, **175,** Dec., 353–359). [This issue].

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

No Waiting in This Long Line. (*Steel*, 1953, **133,** Aug. 3, 124–125). The 365-ft. long continuous annealing line being built for Lukens Steel Co. is described. It comprises a charge table, furnace, transfer table, 1000-ton pressure quench, and a swing discharge table. Stainless steel or clad plates up to 2 × 130 × 480 in. will be handled. The 200-ft. roller-hearth furnace will be used to give heat-treatment up to 1950° F. Silicon carbide rolls are being developed for use at the high temperatures.—D. L. C. P.

New Heat Treat Line Meets Many Varying Requirements. (*Steel Processing*, 1953, **39,** May, 243–245, 251). A newly installed continuous Sunbeam Stewart hardening, quenching, and tempering line at Interstate Drop Forge, U.S.A., is described and illustrated. The hardening furnace has a maximum operating temperature of 1550° F. and a usable heating space of 30 in. × 10 ft. The work is conveyed through the furnace, and drops into either water or oil quench tanks, from which a second conveyor transfers it on to the moving hearth of the tempering furnace. This has a maximum operating temperature of 1200° F. and a usable heating space of 36 in. × 16 ft. The furnace burners are designed for either natural gas or light fuel oil.—P. M. C.

Heat-Treating Furnaces Help Save Critical Materials. F. H. Bremmer and F. J. Zehnder. (*Indust. Heating*, 1953, **20,** May, 913–916). A casing for deep oil wells, usually made of normalized and tempered high-manganese molybdenum steel has, for the past five years, been successfully produced from plain carbon steel. The new process, using a continuous heat-treating, quench, and tempering line is described. This comprises two furnaces consisting of a series of high-intensity radiant gas-fired furnace sections and quench head. Details of the tempering furnace, carburettors, and control instruments are given.—B. G. B.

Handling of Heavy Bar Stock. F. von Trotha. (*Indust. Heating*, 1953, **20,** May, 886–888). Improved loading and unloading conditions with bar stock are obtained by using a slot type box furnace, shallow in depth and wide enough to accommodate the longest bars. Silicon carbide rails serve as the hearth.—B. G. B.

Precise Heat Treatment of Jarvis High-Speed Taps. (*Indust. Heating*, 1953, **20,** May, 892–894). Two electric hardening furnaces are used, the hardening time at 2250–2375° F. varying with the size of the tap. Temperatures are controlled by single-record electronic strip chart potentiometers. The taps are quenched in oil and tempered in an electrically heated salt bath at 1050° F. Accurate control throughout ensures uniform hardness.—B. G. B.

Heat-Treatment of Stainless Steels. L. F. Spencer. (*Indust. Heating*, 1953, **20,** Jan., 42–50; Feb., 220–224; Apr., 678–690; May, 879–884). The basic types of stainless steels are considered. They are divided into three groups: (*a*) The chromium–nickel or austenitic grades; (*b*) the hardenable or martensitic grades; and (*c*) the non-hardenable or ferritic grades. Basic furnace practice is discussed. The problems of scale formation and carburization are dealt with, and the merits of different types of furnaces are considered. The heat-treating cycles for the above three types are outlined. Nitriding the stainless steels by the 'Malcomizing' treatment, and pickling and passivation after heat-treatment are also discussed.—B. G. B.

Combination Heat-Treatment Plant. (*Indust. Gas*, 1953, **16**, Mar., 166–174). Details are given of a new American gas-fired heat-treatment furnace with a heating chamber 24 × 36 × 15 in. The furnace, suitable for temperatures up to 900° C., is heated by town gas giving into radiant tubes. Tables are given indicating the results to be expected from this furnace.—D. H.

Multiple Forms Provide Internal Control for Commercial Heat-Treating Plant. C. H. Hewitt. (*Metal Treating*, 1953, **4**, May–June, 7, 33). The use of a multiple form, which comprises triplicate invoices, four copies of works instructions, a packing slip and delivery receipt, is described. Sections of the form follow the work through the plant, while others are maintained in their appropriate departments for correlation when the work is completed.—P. M. C.

Protective Atmosphere Generators and Electric Protective Atmosphere Furnaces for the Heat-Treatment of Steel. T. Türk. (*Elektrowärme-Techn.*, 1953, **4**, July, 89–91). Continuation of a series of articles (*see J. Iron Steel Inst.*, 1953, **175**, Oct., 223). Recent types of furnaces and protective gas generators for: (1) Annealing steel tubes, rods, austenitic steel wire; (2) bright-annealing various components; (3) carburizing, nitriding and tempering; and (4) sintering powdered metals are described. Their performance and novel features are discussed.—P. F.

Unsatisfactory Heat Treating Result—Their Causes and Prevention. M. Balicki and A. O. Moelk. (*Metal Treating*, 1953, **4**, May–June, 2–4). The authors have here listed all conceivable defects, *e.g.*, cracks, disintegration, distortion, etc., and all causes. Each is given a classification letter and number. The hope is expressed that, through active co-operation of heat treaters and metallurgists, the causes chiefly responsible for the various defects may be identified.

Putting the Heat on Jet Engine Parts. (*Steel Processing*, 1953, **39**, Feb., 83–86, 95). Descriptions and illustrations are given of four new large furnaces specially installed at Ryan Aeronautical Co., San Diego, for stress-relieving treatments on rocket motors and jet engine parts. A large General Electric Co. furnace has an unusual loading car which is hoisted 9 ft. above the factory floor and forms the furnace bottom. A Lindberg continuous furnace which has two separate compartments for heating and cooling can operate at 2100° F., and is heated by 'Globar' elements.—P. M. C.

A New Test Piece for Heat-Treatment Studies. M. Arrighetti. (*Fonderia Ital.*, 1953, **2**, May, 435–441). After critically reviewing various test pieces for the study of heat-treatment, the author suggests a new and simple one. It is easy to cast; the metal solidifies rapidly; and the cost is low. A complete specification is given for the manufacture and use of this test piece, which is wedge shaped, 15 mm. wide at the thick end, 120 mm. long, and 40 mm. deep.—M. D. J. B.

Heat-Treatment of Ductile Cast Iron. K. D. Millis. (*Metal Treating*, 1953, **4**, Jan.–Feb., 6–8). Details are given of several annealing, and normalizing and quenching treatments which are suitable for ductile cast irons. Typical properties for correctly annealed material are 65,000–70,000 lb./sq. in. tensile strength, 15–25% elongation, and a Brinell hardness of 170 or lower. Properties are tabulated for irons quenched and tempered at different temperatures. Tensile strengths up to 220,000 lb./sq. in. and hardnesses up to 430 Brinell are attainable.—P. M. C.

Cast Iron—A Study of Dispersed Cementation. A. Guédras. (*Mét. Constr. Mécan.*, 1952, **84**, Dec., 929–939; 1953, **85**, Jan., 27–33; Feb., 105–110; Mar., 181–189; Apr., 269–273). A detailed examination is made of the dispersed cementation process. The influence of elements other than carbon in the process is considered, and cementation by carbon and other substances is reviewed. The structure of the metal is as important as the chemical composition in determining the penetration. The use of different lead salts in the process is discussed and the results obtained with them are considered. The impregnation of the metal with lead gives an excellent resistance to wear.—B. G. B.

Natural Gas and Propane-Air Gas in the Heat-Treating Industry. P. E. Peacock, jun. (*Metal Treating*, 1953, **4**, Jan.–Feb., 2, 3, 25). A brief appraisal is given of the uses and applications of natural and propane-air gases to scale-free heat-treatment and gas carburizing. Arrangements for storing, vapourizing, and mixing propane-air are shown by diagrams.—P. M. C.

Records System for a Heat-Treating Plant. C. H. Muehlemeyer. (*Metal Treating*, 1953, **4**, Jan.–Feb., 9, 10). A record system is described which provides production, despatch, and invoicing departments with full particulars of requirements and specifications for each job passing through the plant.

The Production of Sheets and Bars of Low Coercivity and High Magnetic Permeability from Low-Carbon Steel. (*Biuletyn Informacyjny Instytutow Ministerstwa Hutnictwa*, 1953, **4**, 2, 5–7; *Hutnik* (Katowice), 1953, **20**, 2). [In Polish]. Experimental production on an industrial scale of sheets and bars of low coercivity and high magnetic permeability from low-carbon steel (C 0·07–0·16%, Mn 0·31–0·45%, Si 0·22–0·24%, P 0·022–0·028%, S 0·025–0·027%) is described. The decarburization of sheets and bars was done by 25 hr. heat-treatment at 780–800° C. in closed boxes and pipes, respectively. Before decarburization, sheets and bars were covered with an oxide film by passing them through a normalizing furnace. The experiments showed that sheets up to 3 mm. thick with coercivity of 0·5 oersted could be produced from the steel usually available.—V. G.

Decarburization of Transformer Steel. (*Metal Treatment and Drop Forg.*, 1953, **20**, Mar., 111, 112). The continuous bright annealing and decarburizing of cold-rolled silicon steel strip, at the Panteg Works of Richard Thomas and Baldwin's Ltd., is described. The carbon content of the strip is reduced from 0·05% to below 0·008% by treating in a special moist atmosphere, containing closely controlled water vapour and hydrogen.—P. M. C.

The Formation of Silicon "Fur" on Transformer Sheets. E. Günther. (*Met. u. Giesserei Techn.*, 1952, **2**, Oct. 354–355). The name 'silicon fur' is given to a type of scale which forms on certain kinds of high-silicon steel sheet after annealing which is characterized by its poor adhesion to the metal, its abnormal thickness, and the fact that it is less acid soluble than ordinary scale on this type of sheet. Several examples of its formation are given; excessive annealing temperatures are blamed.—L. J. L.

Apropos Martempering. B. F. Harvey. (*Mét. Constr. Mécan.*, 1953, **85**, June, 483–485). The basic principles of the martempering process are described; the process involves a type of martensitic tempering of the steels in two stages. For a steel containing 1·25% C, 0·35% Mn, 0·03% P, 0·30% Si, 0·03% S and 1·25% W, for use as saw blades, the following treatment was used: Holding for 2 min. at 793° C. in a salt bath followed by 3 min. at 293°C., and quenching in air; this gave a Rockwell hardness of 67 C.

Induction Heating. L. F. Spencer. (*Steel Processing*, 1953, **39**, Jan., 22–28, 42, 43; Feb., 71–75). Three types of equipment, the motor generator set, the spark gap converter, and the vacuum tube converter, are described, and the basic principles of the induction method of heating are outlined. Specific applications to hardening processes, soldering and brazing, and heating for forging are dealt with. The types of equipment most suitable for various applications are tabulated. (13 references).—P. M. C.

Micro-Induction Hardening by Means of High Frequency Impulses. W. Thorwart. (*Z.V.d.I.*, 1953, **95**, Apr. 15, 341–344). In order that hardening of small parts should be only skin deep, an impulse induction heater needs to be used impulsively. Applications to current studies are suggested and apparatus is briefly described.—J. G. W.

Induction Hardening of Gear Teeth. D. W. Brown. (*Machinist*, 1953, **97**, Apr. 25, 653–657). The design of coils for the induction heating of gear teeth is discussed with descriptions of several types of coil and the profiles of the hardened zone obtained with them.—R. A. R.

High-Frequency Induction Bar-Hardening Machine. (*Engineering*, 1953, **176**, July 24, 121). This article describes a General Electric Co. high-frequency induction hardening machine for the surface hardening of high-carbon and alloy steel bars.—M. D. J. B.

High-Frequency Induction Heating. H. A. Codelli. (*Canad. Metals*, 1953, **16**, Apr., 18–20; May 20, 24–26). This article presents a limited, basic discussion on the operation of an electronic high-frequency generator and its application to brazing, soldering, hardening, carburizing and other forms of heat-treatment.—J. C. B.

Efco Heat-Treatment Division. (*Machinery*, 1953, **83**, July, 10, 83–85). A new induction heat-treatment division of the Electric Furnace Co., Ltd. is described. Work in

progress includes small pins, plain shafts, and cast iron cylinder liners which are hardened internally by the scanning method. Equipment for degreasing machined components and for phosphate coating is also installed.—E. C. S.

Dual-Frequency Induction Heating Lowers Process Costs. R. S. Segsworth. (*Iron Age*, 1953, **171,** Apr. 16, 113–116). A new concept in induction heating, using dual frequencies has reduced capital outlay and operating costs. The method uses two sets of continuous coils, a low-frequency heat tunnel being followed by a high-frequency section. Low-frequency current is taken directly from a 50- or 60-cycle main. In one installation one man heats 200 billets per hour to forging temperature; there is less scaling and little space is required.

A Survey of Industrial Carbonitriding Practice. M. B. Bever, C. F. Floe, and W. G. Zaruba. (*Indust. Heating*, 1953, **20,** Feb., 256–264 ; Apr., 650–660 ; May, 872–874, 994). An outline of the general applications of the carbonitriding practice, as determined by a survey of 15 industrial installations, is presented. The furnaces, atmospheres, and cycles used in industrial carbonitriding are considered in some detail. Properties of carbonitrided cases, apart from routine tests of hardness and case depth, are being explored by service performance, but some laboratory tests seem to be desirable.

Features Most Desirable in Batch Carbonitriding Equipment. G. C. McCormick and C. E. Wenger. (*Metal Treating*, 1953, **4,** May–June, 5, 6). Features which are desirable in a modern, batch carbonitriding unit are discussed very briefly under the following headings : Ability to change temperature rapidly ; fast heat recovery time ; effective atmosphere protection; quenching ; controlled quench-oil temperature ; simplified maintenance; and organized handling of stock.—P. M. C.

Stress-Relieving of World's Largest Air Compressor Discs. L. E. Anderson and J. F. McCarthy. (*Indust. Heating*, 1953, **20,** May, 862–870, 1000). An unusual furnace designed for stress-relieving treatment is described. The discs are supported in the furnace by portable steel stands and 12 Tate-Jones Universal burners are used to underfire and overfire the discs. Temperature control is by six chromel-alumel thermocouples. The discs are heated to 1020° F. at 30° F./hr. and are held at this temperature for 10 hr. This furnace has been used satisfactorily for other heat-treatments including normalizing.—B. G. B.

Uniform Annealed Grain Size Obtained with Radiant-Roof Furnace. C. R. MacWhirter. (*Iron Age*, 1953, **171,** Apr. 23, 144–146). A pan type annealing furnace has a roof constructed with 27 heavy-duty radiant burners arranged in lateral rows of five and four alternately. Work temperature uniformity has been obtained by progressively throttling burners in each row from the sides towards the centre. Once adjusted, each continues to develop to proportionate share of heat as the zoned temperature controls are altered. The significance of this type of furnace is that no grain-size differences in samples taken throughout a pan load can be detected.—A. M. F.

Stress Relieving Furnace at Birkenhead. (*Welding and Metal Fab.*, 1953, **21,** June, 205–206). A furnace installed by Cammell Laird and Co. Ltd., Birkenhead, for stress relieving welded structures up to 29½ ft. long by 14 ft. wide and 15½ ft. high is described. It is heated by top and bottom banks of forced blast burners on each side.—R. A. R.

Stress Relief of Welded Structures: Heat-Treatment Done *in Situ*. G. Wellensiek and F. C. Evans. (*Iron Coal Trades Rev.*, 1953, **166,** May 1, 1007–1009). Following the fracture of a welded branch of a pipeline system serving a hydro-electric power station in Germany, all the welded branches were stress-relieved *in situ*. The authors give details of the method employed and of the technique of stress-relieving.

Experience with Oxy-Acetylene Stress-Relieving of Pressure Vessels. H. Kunz. (*Schweissen u. Schneiden*, 1953, **5,** June, 216–225). Experience in the stress-relieving of welded pressure vessels is discussed. After stress relieving, using oxy-acetylene burners followed by a water spray, residual stresses were determined. A decrease in longitudinal stresses of 69–80% and of vertical stresses of about 60% had been achieved.—U. E.

The Annealing of Arc-Welded Seams in Boilers. F. Gentner. (*Schweissen u. Schneiden*, 1953, **5,** June, 211–216). A review is given of the present position of regulations for annealing welded vessels. The mechanical properties of as-welded, annealed, stress-relieved, and air-hardened arc welds were investigated and compared with those of converter steel.—U. E.

Annealing Tests on Cold-Rolled Low-Alloy Strip Steels in Pot, Muffle, and Continuous Annealing Furnaces. A. Pomp, G. Niebch, and J. G. Brockhaus. (*Stahl u. Eisen*, 1953, **73,** May 7, 646–653). Tests on a variety of low-alloy steels, cold rolled with reductions of 10–40%, in an industrial pot furnace, and in a muffle and a continuous furnace, have been carried out to determine the effect of temperature, time, and amount of cold work on mechanical properties. Recommendations are made for the best methods of annealing these steels.

Instrumentation Simplifies Annealing. H. C. McKinnon. (*Steel*, 1953, **132,** May 25, 128–130). The production of high quality steels at Atlas Steels Ltd., is briefly described. Details are given of the instrumentation and automatic control of a four-zone furnace for annealing stainless steel sheet and plate.

Distortion Control and Hot Oil Quenching. F. E. Harris. (*Metal Treating*, 1953, **4,** Mar.–Apr., 5, 10). The use of hot oil, (350–400° F.), to reduce the temperature difference between steel parts and the quenching bath is discussed. The heating, volume, and circulation of the oil, and the use of protective atmospheres to ensure cleanliness of the steel surface are considered.—P. M. C.

A Cooperative Research Programme on Quenching. V. Paschkis. (*Metal Progress*, 1952, **62,** Dec., 93–96). The background, purpose, and organization of a research project on quenching now being undertaken at Columbia University are described.—B. G. B.

FORGING, STAMPING, DRAWING, AND PRESSING

Forging World's Largest Air Compressor Discs Involves Special Problems. (*Indust. Heating*, 1953, **20,** May, 854–860). The discs, 18 ft. in dia. and 9 in. thick, weighing 50 tons, are to be used in air compressors for supersonic wind tunnels. A 92 in. ingot of alloy steel was forged on a 7500-ton forging press. Details of forging procedure, including the forming of lips on two sides of the forging, are given. The final annealing treatment was carried out at 1120° F. and rough machining was done on a large vertical boring mill.—B. G. B.

Forging in East Africa. S. R. Godwin. (*Metal Treatment and Drop Forg.*, 1953, **20,** May, 219–222). A description is given of the forges of the chief mechanical engineer's section of the East African Railways and Harbours, Nairobi, where a high percentage of native labour is employed. Drop-forging, press-work, general forging and spring making are undertaken, the scope of the work ranging from locomotive motion gear down to $\frac{1}{16}$ in. springs for gauges. The plant includes three Brett friction-lift stamps of 15, 7 and 5 cwt. capacity, a 150-ton hydraulic combination press, a 1¼ in. dia. capacity heading machine, four steam hammers of 40, 25, 15, and 5 cwt. capacity, two pneumatic hammers of 20 and 7½ cwt., and a 200-ton hydraulic horizontal press.—P. M. C.

How to Fabricate 430 Stainless. L. F. Spencer. (*Iron Age*, 1953, **171,** Apr. 23, 139–143). Because it lacks nickel, stainless steel 430 is harder to form than No. 302. It has about three-fourths the formability of a low-carbon deep-drawing steel. Reduction on a cupping operation is between 20 to 25% and 15% in redrawing operation. Press drawn parts will need larger blank sizes, higher hold down pressures and increased radii. Clearances in blanking or punching are usually the same as for low-carbon steel. Greater leverage may be required in spinning and speeds will run at 60 to 70% of speeds for mild steel.—A. M. F.

The Hot Forging of Metals. H. K. Barton. (*Machinery*, 1953, **82,** June 12, 1109–1113). Two factors contribute to the difficulty of maintaining adequate registration throughout the working life of the tool in impact-forging: (1) Unavoidable vibration on impact ; and (2) the tendency of the top tool to move laterally in the direction of greatest metal flow. Methods of reducing the latter are discussed. Methods of reducing frictional resistance to overflow of the metal, flash formation, and reduction of pressure on the flash are considered.—E. C. S.

Stellite in the Forging Industry. M. Riddihough. (*Welding and Metal Fab.*, 1953, **21,** July, 242–244). The maintenance of forging tools is discussed with reference to the use of Stellite as a hard-facing material.—U. E.

How to Construct the Foundations for Power Hammers. I. E. Katel. (*Rev. Met.*, 1953, **50,** June, 373–381). Suitable design of foundations gives increased efficiency while avoiding cracking of the foundation. Three constructions are considered : (1) An anvil block separated from the foundation

by oak beams : (2) an anvil block resting on an iron slab on a sunken foundation ; and (3) as (2) but with a reinforced cork layer between the foundation and the ground. From a study of loss of active energy, maximum pressure on the ground, and the natural frequency of the foundation, it is concluded that the third arrangement is the best.—A. G.

Large-Diameter Line Pipe. W. C. Hoppe. (*Mech. Eng.*, 1953, **75,** Feb., 114–116). Large steel tubes up to 36 in. in dia. are fabricated by the A. O. Smith Corp., Milwaukee, by trimming the edges of the flat plate, pressing the plate into a tube in three stages, and flash-welding the seam. The tube is then expanded 1 to 1·25% circumferentially within cylindrically bored dies which increases the yield strength so that a minimum of 52,000 lb./sq. in. can be guaranteed.—R. A. R.

How to Make Carbide Cold-Heading Dies. A. E. Glen. (*Machinist*, 1953, **97,** May 30, 888–890). Details of the application of cemented tungsten-carbide inserts in cold heading dies and hammers are given with particular reference to the production of small bolts and screws up to $\frac{1}{4}$ in. in dia. and rivets up to $\frac{3}{8}$ in. in dia.—E. C. S.

Radial Forming Gets Added Muscle. (*Steel*, 1953, **132,** June 29, 112–113). A hydraulic machine capable of exerting radial forces of 4800 tons has been built for expansion forming large parts, after a 1200-ton machine proved a success. Expanding mandrels allow large components for jet engines and other turbine power plants to be accurately pressed from heat-resistant, stainless steel alloys.—D. L. C. P.

Stampings: Cheaper Production by Improving Design. F. Strasser. (*Iron Steel*, 1953, **26,** May, 183–187 ; June, 303–307). The author shows how the production of stampings can be made cheaper by close collaboration between the article designer and the tool engineer, giving many examples of the economical and practical results of such collaboration.

Cold Extrusion of Steel—A Military Hero in Civilian Garb. R. F. Huber. (*Steel*, 1953, **133,** July 27, 78–82, 109–110). This is a general survey of modern American practices in cold extrusion. Applications are being extended to larger parts and new steels. The car and ordnance industries are particularly concerned. The principle of the method, the type of parts which can be made, and the tools and equipment needed are described, with examples.—D. L. C. P.

Cold Extrusion Ready to Invade Metal Working Markets. D. I. Brown. (*Iron Age*, 1953, **171,** Apr. 23, 152–155). A brief description is given of the ' Koldflo ' extrusion process. This is a process for cold shaping under compression by a combination of forward and backward displacement, coining, expanding and ironing.—A. M. F.

How National Tube Hot Extrudes Stainless Steel Tubing. D. I. Brown. (*Iron Age*, 1953, **171,** Mar. 19, 129–133). At the Gary Works seamless tubes in various grades of stainless steel $1\frac{1}{2}$ to $3\frac{1}{2}$ in. in dia. and 20 to 40 ft. in length are being made by the Ugine-Sejournet process. So far production rates are as high as 40 extrusions per hour. Billets are first drilled or pierced and then heated to 2300° F. in a vertical furnace, handling in the salt bath being automatic. The main ram in the press carries a force of 2000 tons at 30 in./min. and reduction ratios as high as 50 to 1 have been used, but 35 to 1 is preferred to reduce wear.—A. M. F.

New Tester Accurately Checks Drawability of Sheet Steel. W. G. Patton. (*Iron Age*, 1953, **171,** Mar. 29, 143–145). A description is given of the Flex-Tester made by Steel City Testing Machines Inc. This instrument is used to bend the corner of a sheet of steel to a specified arc. Resistance to bending, sheet thickness and maximum curvature are combined to given an index of the drawability of the sheet. The method is rapid and 95% accuracy of prediction may be expected.—A. M. F.

Lubricants For Drawing Metals. A. A. Brown. (*Iron Steel Eng.*, 1953, **30,** June, 96–100). The author discusses drawing operations in general and examines the requirements of lubricants for drawing. Stress is laid on the important rôle played by the fatty oils and their derivatives in these lubricants.—M. D. J. B.

Producing Gas Turbine Parts with Minimum Metal Wastage. C. J. Bath. (*Machinery*, 1953, **82,** June 12, 1101–1105). The radial draw-forming process permits rapid production of circular parts of light cross-section to close dimensional tolerances with minimum wastage of metal. Outer combustion chamber liners for gas turbines are made by this process from Stellite sheet $3\frac{5}{8}$ in. wide by 0·040 in. thick, of Rockwell C28 hardness, and tensile strength 125,000 lb./sq. in. The set up for producing gas turbine rings from 93% pure titanium is illustrated. Most parts formed for gas turbines are made from stainless steel having a tensile strength of 100,000 lb./sq. in.—E. C. S.

Checking Wire Drawing Dies. (*Metal Ind.*, 1953, **82,** May 22, 417, 418). A cheap and simple instrument for determining die angles and for examining die wear is described. Designed by B.I.S.R.A., this ' Profiloscope ' is simple and robust enough for use in the die shop, in contrast with the B.I.S.R.A. Profilometer which was designed some years ago as a highly accurate research tool. In the Profiloscope a narrow beam of light is projected through the die onto a ground glass screen. The resulting image, which may be varied by tilting the die through measured angles, enables the die angle to be determined to $\pm 0{\cdot}5$. A good picture of the die wear is also obtained.—P. M. C.

ROLLING-MILL PRACTICE

Consett Development: New Blooming, Slabbing and Billet Mills. (*Iron Steel*, 1953, **26,** May, 162–168 ; June, 309–314). New developments at the Consett Iron Co. Ltd. centre round the installation in straight-line layout of a Davy-United blooming and slabbing mill, followed by a Morgan continuous billet and slab mill in two separate groups of six and four stands respectively. The general layout is outlined and the various items of the new plant are described in detail.—G. F.

Resorted Slabbing Mill Attains High Output. S. Elliott. (*Iron Age*, 1953, **171,** Apr. 16, 118–120). Rehabilitation of a 36-in. slabbing mill is described. New type bottom-fired recuperative pits have reduced fuel consumption from 16 to 7 therms/ton. Two new soaking-pit cranes and new manipulators have reduced the mill handling time. Other new equipment includes an approach table, depressing table, lift and piler table. Concrete troughs flushed with 10,000 gal./min. remove scale and debris to a sump.—A. M. F.

Rod Mill Combines High Speed, Top Quality. (*Steel*, 1953, **133,** July 20, 90–93). A brief description is given of a rod mill, which has been reorganized to give exceptionally high production rate of 0·218–0·656 in. rod from $2\frac{1}{2} \times 2\frac{1}{2}$ in. billets. The plant is essentially a 3-strand unit and includes three 180° turns to shorten the line. Details show how the 22 stands are used to give products of various sizes.—D. L. C. P.

Deep Drawing Steel Sheet Surface Quality. R. J. Walter. (*J. Met.*, 1953, **5,** May, Section 1, 630). The production of deep-drawing aluminium-killed steel sheets is briefly discussed with special reference to the care to be taken in rolling to prevent surface defects.—R. A. R.

Armco Steel Co. Operates New Hot Strip Mill at Ashland, Kentucky. (*Blast Furn. Steel Plant*, 1953, **41,** July, 770–771). **Strip Mill with Designed-in Extras.** (*Steel*, 1953, **132,** June 15, 102–108). **Armco Starts Operation on New 80-in. Hot Strip Mill at Its Ashland Plant.** (*Iron Steel Eng.*, 1953, **30,** June, 115–116). This new mill, which is described briefly, is an 80-in. hot strip mill with a capacity of 150,000 tons of finished steel per month. The mill is designed to roll down 10 ton ingots. Constructional work is continuing on a plant for the continuous coating of steel strip with zinc.—B. G. B.

The Reversing Hot Strip Mill. A. F. Kenyon. (*Iron Steel Eng.*, 1953, **30,** June, 62–70). The author describes the arrangement and operation of reversing hot strip mills and discusses some typical installations, including electrical equipment. Their moderate capital cost and economical operation make them an attractive proposition for moderate tonnages.—M. D. J. B.

Design and Practices of the Semi-Continuous Strip Mill. H. H. Warnock. (*Iron Steel Eng.*, 1953, **30,** June, 57–60). The author describes the 48-in. four-stand semi-continuous strip mill at the Youngstown plant of Republic Steel Corp. This mill provides a good example of improvements carried out at minimum cost. The new mill has an output of over 100 tons/hr.—M. D. J. B.

MACHINERY FOR IRON AND STEEL PLANT

Radio Control of Cranes and Hoists. L. Roberts. (*Mech. Handling*, 1953, **40,** June, 289–292). A review is given of the principles and applications of radio control to various types of crane and hoist.—D. H.

Heavy Duty Plate Bending Machine. New Design Introduced by Joshua Bigwood. (*Welding and Metal Fab.*, 1953,

21, July, 252–253). A new 3-roll pyramid type plate bending machine which will take plates up to 18 ft. wide and ¾ in. thick is described. The top and bottom rolls are 18 and 15 in. in dia. respectively.—R. A. R.

LUBRICANTS AND LUBRICATION

Application of Oil Lubricants to Plain Bearings. L. Ballard. (*Machinery*, 1952, **82,** June 5, 1057–1059). The design of bearings and methods of applying lubricants, including drip feed oilers, bottle oilers, ring-oiled bearings, splash lubrication, circulation systems, mechanical force-feed lubricators, and waste-packed bearings, are briefly discussed.—E. C. S.

The Structure of Lubricating Greases and Its Control. J. B. Matthews. (*J. Inst. Petroleum*, 1953, **39,** May, 265–275). Recent work concerning the structure of conventional lubricating greases made from soaps and hydrocarbon oils is discussed.—B. G. B.

Thixotropy of Lubricating Greases. B. W. Hotten and B. B. Farrington. (*Amer. Soc. Test. Mat. Bull.*, 1953, Apr., 53–56). A simple test has been developed for the measurement of the thixotropy of lubricating greases. Shear softening and age stiffening are measured separately. Typical lithium, sodium, calcium, barium, and aluminium soap greases were measured.—B. G. B.

Central Greasing Station for Electric Overhead Travelling Cranes. L. R. Evans. (*J. Iron Steel Inst.*, 1953, **175,** Dec. 419–420). [This issue].

On the Solution of the Reynolds Equation for Slider-Bearing Lubrication.—III. Effect of Transverse Curvature. A. Charnes, E. Saibel, and A. S. C. Ying. (*Trans. Amer. Soc. Mech. Eng.*, 1953, **75,** May, 507–513).—D.H.

The Refining and Re-Use of Used Oils. P. M. E. Schmitz. (*Rev. Tech. Luxembourg.*, 1953, **45,** Apr.-June, 73–84). Methods employed for the treatment of used lubricating oils are described, including treatment with acid, filtration, and active earths.—B. G. B.

WELDING AND FLAME-CUTTING

Core Wires for Welding Electrodes. K. L. Zeyen. (*Draht*, 1953, **4,** Apr., 130–135). Compositions and properties of welding electrode wires are discussed with reference to the standards of ten countries.—J. G. W.

Electrodes for Welding 18% Cr–8% Ni. H. F. Tremlett. (*Welding and Metal Fab.*, 1953, **21,** Apr., 136–144). The factors affecting weld decay in unstabilized 18/8 parent metal are discussed. They are shown to be carbon content of steel, reheating period at 650° C., and period in the corroding solution. Standard weld decay tests for parent steel and electrodes are described. The prevention of weld decay in parent metal is considered with emphasis on the requirements of a minimum titanium/carbon ratio.—U. E.

A Modern Fabrication Shop. (*Welding and Metal Fab.*, 1953, **21,** July, 231–237). An illustrated account is given of the new fabricating shop of Ashmore, Benson, Pease and Co., Ltd., Stockton-on-Tees. The floor area is 132,000 sq. ft. set out in six bays each of which is piped all round with acetylene, oxygen, and compressed air. Welding is a major feature. The equipment includes guillotines, plate levellers, radial drills, oxygen cutting machines, plate edge planers, and bending rolls.—R. A. R.

Welding in Marine Engineering. H. N. Pemberton. (*Proc. Inst. Mech. Eng.*, 1953, **167,** No. 1, 48–61). The author surveys and comments on the use of welding for the construction and repair of marine machinery for main propelling and ancillary purposes. The history of welding in relation to marine engineering is traced from the hammer welding of boiler seams in 1870 up to the present day, when welds made by modern processes are accepted for highly stressed components.—P. M. C.

Flash Welding High Tensile Steel Tubes—Temperature Measurements. H. Brooks. (*Welding and Metal Fab.*, 1953, **21,** May, 177–184). Measurements have been made to determine the effects of process variables on the temperatures produced in high-tensile alloy steel tubes by the flashing phase of the welding cycle. The most important effects are those of flashing distance and speed. Initially, increases of flashing distance cause large temperature rises. Average interface temperatures approximating to the steel melting point can only be obtained at flashing speeds of about 1·0 in./min. and higher.—U. E.

Steels for Welding. G. Erber. (*Mech. World*, 1953, **133,** May, 210–212). Factors affecting the weldability of high-tensile steel are given. Some typical high-tensile weldable steels are mentioned.—D. H.

Recrystallization Welding. J. M. Parks. (*Welding J.*, 1953, **32,** May, 209s-222s). Recrystallization is established as the mechanism of solid phase welding. The principal factors controlling recrystallization are discussed and related to welding. Data on the shear strength of these welds are presented. A basic relationship between recrystallization temperature and degree of deformation is derived and analysed.

New Arc Welding Process for Cast Iron. K. K. Khrenov and F. S. Vol'fovskaya. (*Avtog. Delo*, 1952, **23,** No. 1, 3–6). In the process described, the arc from a carbon electrode is directed on to a copper or copper alloy filler rod, and, as the filler metal melts off and spreads over the iron to be welded, the arc and rod are advanced. Results of mechanical tests on welds are presented.—R. A. R.

Pipe Formation in Weldments. S. E. Erikson and T. Norén. (*Svetsaren*, 1953, **18,** 1, 1–9). [In Swedish]. It is impossible to avoid pipe formation in the crater at the end of the welding run. The nature of this crater is described and investigations are reported to show that 'after-filling' is the only way to deal with the difficulty.—R. A. R.

Automatic Arc Welding. Principles and Applications of the "Lincolnweld" Process. J. Burrows. (*Welding and Metal Fab.*, 1953, **21,** July, 246–251). The automatic submerged arc welding process is discussed. This process is used for the fabrication of axle housings, ships' bulkheads, deck plate, circular bobbins, road roller wheels, and pressure vessels.—U. E.

Welding of High Alloys Doubled with New Roll-Spot Technique. J. R. Fullerton. (*Mat. Methods*, 1953, **37,** Feb., 166, 168, 170). Brief details are given of modifications carried out on the drive mechanisms of Taylor-Winfield standard seam welders. Gas-tight seams can now be produced at 26 in./min. compared with 12 in./min. formerly achieved.—P. M. C.

Spot Welding of Mild Steel (En2C) and 'Corben' Low Alloy Steel for Structural Purposes. W. S. Simmie. (*Welding and Metal Fab.*, 1953, **21,** May, 170–174). Spot welding was carried out on En2C and Corten (a copper-bearing steel) steels. Tension and hardness tests and metallographic examinations show that En2C and Corten steel can be successfully spot welded when automatic post heat-treatment is applied.—U.E.

On Estimating the Strength of Spot Welds from their External Appearance. E. A. Greil'. (*Avtog. Delo*, 1950, No. 12, 10–13). [In Russian]. The following are the main conclusions drawn from an investigation of the strength of spot welds produced in structural steel by welding from two sides with electrodes of different diameters. Distinct and circular temper-colour rings on the thick-electrode side indicate a strong weld. A one-sided imprint of the upper (thinner) electrode points to abnormal dissipation of heat leading to a poor joint; the depth of the imprint cannot be used as a measure of the strength of the weld.—S. K.

Investigation of the Fatigue Strength of Welded Studs Compared with that of Threaded Studs. F. Koenigsberger and Z. Garcia Martin. (*Ciencia tecn. Soldadura*, 1953, **3,** May–June). [In Spanish].

Controlled Thermal Severity Cracking Test Simulates Practical Welded Joints. C. L. M. Cottrell. (*Welding J.*, 1953, **32,** June, 257s–272s). A description is given of a simple test for hard zone cracking in arc-welded low-alloy steel. Experiments were made with restrained fillets, unrestrained fillets, structural joints, and the C.T.S. (Controlled Thermal Severity) test. Various tests were examined and compared with structural joints, rate of cooling in the hard zone being used as a basis for comparison. The results indicated a relationship, when using a given steel and electrode, between rate of cooling at 300° C. in the hard zone and incidence of hard zone cracking. The C.T.S. test was used to derive an empirical equation which relates rate of cooling in the hard zone to fillet size (single run) and shape of the welded joint.—U. E.

Gas Produced by Inert Arc Welding. J. J. Ferry and G. B. Ginther. (*Welding J.*, 1953, **32,** May, 396–398). An investigation of gases and vapour which may be produced by the inert arc welding process has been made. Oxides of nitrogen were not produced in significant amounts but ozone was

produced in significant concentrations. Trichloroethylene vapour was decomposed into phosgene and other products. The use of argon rather than helium greatly increased the formation of ozone, nitrogen oxides, and trichloroethylene decomposition products.—U. E.

To What Extent Does Stress Relieving Occur at 200-300° C.? R. Gunnert. (*Welding J.*, 1953, **32**, June, 292s–301s). The stress-relieving of welds at a temperature of 200–300° C. was investigated. Heating below 300° C. has a minor effect on the internal stresses of the weld metal, but at this temperature the residual stresses in the base metal were reduced by one third.—U. E.

The Prospects of Oxy-Acetylene Low-Temperature Stress Relieving of Welds of Boilers and Pressure Vessels. W. Mielentz. (*Schweissen u. Schneiden*, 1953, **5**, July, 268–269). The three stress-relieving methods, *i.e.*, normalizing, heating between 600–650° C., and cold working at up to 100–200° C., are discussed.—U. E.

Stress Relief Annealing of Welds Made with Molybdenum Steel Electrodes. E. Uhlir. (*Betrieb. u. Fertigung*, 1952, **6**, Nov., 177–181). Tensile and notched-bar impact strength and ageing properties of welds made from molybdenum steel electrodes are satisfactory for structural welding, but the hardness of the weld is too high and could only be reduced to a satisfactory value by annealing at 680° C. or for 45 hr. at 600° C. Since this is impracticable, the use of these high creep strength electrodes should be confined to applications such as boilers, where the welds will be used at 500° C., or where the whole structure can be normalized.—H. R. M.

Ship Failure Research at The National Bureau of Standards. (*Engineer*, 1953, **195**, June 19, 856–858). The National Bureau of Standards has been assisting a board set up by the U.S. Navy to investigate the design and methods of construction of welded steel merchant ships. In particular, the Bureau has undertaken the examination of plates removed from fractured ships. Tests have been completed on 126 plates taken from 65 such ships and some results are discussed.

The Scientific Problem of Welded Structures. F. Campus. (*Rev. Univ. Min.*, 1953, 9th Series, **9**, May, 213–217). Formulæ which have been deduced from experimental work on butt-welded joints to calculate the total stresses which occur on cooling are discussed. Weldability and brittle fracture are also considered.—B. G. B.

The Latest Progress in Resistance Welding. A. C. Boland. (*Rev. Univ. Min.*, 1953, 9th Series, **9**, May, 263–268). Improvements in the design of resistance welding machines are described.

Results Given by Electrodes with Basic Coatings. W. Bonhomme. (*Rev. Univ. Min.*, 1953, 9th Series, **9**, May, 268–277). The results obtained with welding electrodes with basic cores are superior to those obtained with other types of electrode. Investigation of the cost of welding with basic electrode shows that they are not less economic than ordinary electrodes.

Advances in Welding. Repairing, and Cutting with the Electric Arc. F. Danhier. (*Rev. Univ. Min.*, 1953, 9th Series, **9**, May, 277–286). The different types of electrode used for welding mild steels and alloy steels are discussed. Electrodes for the repair of broken equipment by the addition of weld metal which is subsequently machined, is also considered together with electrodes for use in automatic welding machines and oxygen cutting.—B. G. B.

Advances in Welding with the Oxygen Blowpipe, Cutting with Oxygen and Allied Techniques. T. Courard. (*Rev. Univ. Min.*, 1953, 9th Series, **9**, May, 287–300). The author reviews the techniques of gas welding, descaling with oxygen, oxygen cutting with the addition of iron powder to the flame, and metal spraying.—B. G. B.

Metallurgical Aspects of Welding Problems. A. Portevin. (*Rev. Univ. Min.*, 1953, 9th Series, **9**, May, 375–383). Metallurgical aspects of welding practice and of the performance of welded joints are considered.—B. G. B.

Stud Welding. (*Brit. Eng.*, 1953, **36**, July, 12–14). This general survey of the subject deals with the principles involved, equipment used, fluxing and shielding, size and shape of weldable parts, compositions of stud and base metals for brass, steel, and aluminium welding, properties obtained with steel studs, and the importance of design features when using stud welding.—K. E. J.

Riveting by Resistance Heating. (*Canad. Metals*, 1952, **15**, Oct., 94–95). This method of riveting was developed at the Massey-Harris Co. Ltd. to rivet the 12 bars making the concave part of a combine harvester. It can be applied to the small stud $\frac{7}{16}$ in. square by using a 75-kVA. transformer impulse through a copper alloy electrode which, after locally heating the stud to the welding temperature, applies a blow of 3 tons/sq. in. Cost of the operation has been reduced 40% by this method, and time more than 50%.—J. C. B.

High-Speed Oxygen Parting Cutting. (*Stanki i Instrument*, 1952, No. 12, 31). [In Russian]. A high-speed oxygen cutting process developed by the All-Metal Treatment Research Institute is described by which cutting speeds of 400–2100 mm./min. can be obtained. The method is especially suitable for straight cutting, or on a wide radius, to give vertical or bevelled edges. With low-carbon steel 3–30 mm. thick, cutting speeds can be increased 1·5–3 times. High surface qualities are obtained, and the high-speed method is said to have the further advantage of reducing distortion produced by thermal stresses. A special portable machine for the process is illustrated.—S. K.

MACHINING AND MACHINABILITY

Some Soviet Successes in Research on the Technology of Machining. J. Koloc. (*Strojtrenstvi*, 1953, **3**, 4, 273–274). [In Czech]. A brief survey is made of work done in the Soviet Union on subjects such as chip formation in metal cutting, calculation of cutting resistance, high-speed cutting, machinability of materials, wear and abrasion of cutting tools, and cutting-tool tips.—P. F.

Machining—Theory and Practice. K. G. Lewis and W. Milne. (*Machinery*, 1953, **83**, July 10, 69–75, 94). The machinability of medium carbon alloy steels, stainless steels, and cast iron are discussed, including the effect of microstructure.—E. C. S.

Which Gray Irons for Large Volume Production. E. A. Loria. (*Iron Age*, 1953, **171**, Apr. 9, 131–133). Machining tests have shown that high phosphorus grey iron compares favourably with low phosphorus irons, and steadite has no adverse effects on machinability. In alloyed irons, the presence of nickel has a beneficial effect, but the carbide stabilizing effect of chromium sharply reduces tool life.—A. M. F.

Practical Approach to Optimum Machining. I—Chip Studies Reveal What Happens During Turning. A. B. Albrecht. (*Machinist*, 1953, **97**, June 27, 1037–1041). Tests conducted on a "Mona-Matic" lathe having infinitely variable speeds and feeds, and a maximum spindle speed of 3200 r.p.m. are described. These machines, which are designed for turning speeds well above the usual 350 ft./min. limit, are made by The Monarch Machine Tool Co. Ten micrographs of chips are presented.—E. C. S.

Machinability of High-Speed Steels. E. I. Fel'dshtein. (*Stanki i Instrument*, 1953, No. 1, 29–30). [In Russian]. Experiments are described in which the machinabilities of two high-speed steels were compared with each other and with those of other types of steel. Machinability was determined by the author's method of finding cutting speed when facing under standard conditions. The influence on machinability of the following types of heat-treatment for the high-speed steels was also studied: Simple annealing, isothermal annealing, hardening and high-temperature tempering, annealing after hardening, and tempering. The relatively poor machinability of high-speed steels is ascribed mainly to the very high temperatures, due to high cutting force coupled with low conductivity, produced during the cutting process.

Deformation Work Absorbed by the Work-Piece During Metal Cutting. E. G. Thomsen, J. T. Lapsley, jun., and R. C. Grassi. (*Trans. Amer. Soc. Mech. Eng.*, 1953, **75**, May, 591–603). The deformation work absorbed by the workpiece during metal cutting is analysed. Micrographs show that this is appreciable and may constitute the major energy absorbed when the depth of cut is small.—D. H.

Radioactive Cutting Tools for Rapid Tool-Life Testing. M. E. Merchant, H. Ernst, and E. J. Krabacher. (*Trans. Amer. Soc. Mech. Eng.*, 1953, **75**, May, 549–559). The paper presents a rapid method of measuring cutting-tool life using radioactive isotopes as tracers to measure instantaneous tool wear. The method consists of machining with a tool which has been rendered radioactive by neutron irradiation, collecting the resulting chips, and measuring their radioactivity. Data from tests conducted with various tool materials, work materials, and cutting fluids are presented and analysed.

Electro-Spark Erosion. (*Shipbuilder*, 1953, **60**, Aug., 493–496). This article describes the Sparcatron process for

machining extremely hard materials such as metal carbides, and the new very hard metals. (*See* J. Iron Steel Inst., 1953, **173,** Mar., 306).

Anodic-Mechanical Profile Polishing and the Sharpening of Round-Ended, Hard-Alloy Tipped Cutters. G. P. Slesarchuk. (*Stanki i Instrument*, 1953, No. 4, 20–21). [In Russian]. The following advantages over the abrasion method are claimed for the anodic-mechanical method for polishing and sharpening cutting tools having curved hard-alloy surfaces: (1) Absence of cracks in the hard-alloy plates; (2) possibility of varying finish and surface quality without changing working tools ; and (3) high productivity. Discs of copper, steel or cast iron can be used, and the electrical conditions are varied according to the quality of surface required. In some cases abrasion finishing is recommended.—S. K.

Utilization of High-Speed Steel Scrap. A. G. Yakovlev. (*Stanki i Instrument*, 1953, No. 3, 35). [In Russian]. A simple method of re-using pieces of broken high-speed steel cutters is very briefly described.—S. K.

Faster Grinding with Abrasive Belts. H. N. Acker. (*Canad. Metals*, 1952, **15,** Oct. 46–48). The author gives a general description of backstand grinding using abrasive belts and contact wheels. The latter are dealt with in detail because they differ with the type of work to be done.—J. C. B.

Hydraulic Lathe Cuts Roll-Machining Time. B. A. Wilson. (*Iron Age*, 1953, **171,** Apr. 16, 128–129). Details are given of a 60-in. hydraulic lathe for rolls. Tools are hydraulically controlled for both infeed and traverse and up to three tools can be used. The tailstock is also hydraulically controlled by a cylinder inside it. Rolls up to a hardness of scleroscope 90 are now being machined instead of ground. Cutting speed is up to 50 ft./min. with a tool travel speed of 1 to 2 in./rev.—A. M. F.

CLEANING AND PICKLING

Pickling Equipment in the Manual Galvanizing Shop. H. Rückemesser. (*Draht*, 1953, **4,** Mar., 83–85). Baskets and racks for handling small parts in pickling baths are illustrated and described.—J. G. W.

New Descaling Machine 'Argentina'. (*Draht*, 1953, **4,** Mar., 95–97). A new design of a mechanical descaler is now being developed. It consists of ten pairs of rolls in a long split housing, the axes of each pair being set at different angles.—R. A. R.

Continuous Pickling. G. Rossi-Landi. (*Mét. Constr. Mécan.*, 1953, **85,** Mar., 215–217). A short description is given of a continuous pickling line for the treatment of steel strip.—B.G.B.

A Survey of the Technical and Economical Aspects of Continuous Pickling Lines and the Spent-Acid Disposal Methods Available. P. de Lattre. (*Sheet Metal Ind.*, 1953, **30,** Apr. 313–322 ; May, 365–370). The author describes spent liquor neutralization and precipitation by lime, waste solutions recovery through cooling methods, the physical precipitation process, and recovery processes applicable to the case of spent liquors containing small amounts of ferrous sulphate. Typical industrial plants and their operating costs are described, and finally the possibility of producing sulphuric acid by the action of hydrochloric acid upon ferrous sulphate is considered. This apparently simple regeneration is, however, judged to be impracticable. (12 references).—P. M. C.

Treatment of Metal Finishing Wastes. A. G. Gray. (*Metal Progress*, 1952, **62,** Dec., 77–81). The proper and economical disposal of metal finishing wastes is discussed. Various treatments for waste acid, cyanide wastes and metal-bearing wastes are described. Alkaline chlorination is the most practical treatment for cyanide wastes. The treatment of chromium wastes with sulphur dioxide and the use of ion exchange methods are mentioned.—B. G. B.

The Use of Inhibitors from the Point of View of Brittleness Induced during Pickling. G. Rossi-Landi. (*Mét. Constr. Mécan.*, 1953, **85,** Jan., 59). The use of inhibitors to reduce the production of hydrogen during the pickling of metals is briefly considered.—B. G. B.

Modern Pickling Plant for the Wire and Bar Industry. N. Swindin. (*Wire Industry*, 1953, **20,** Apr., 409–413). The following topics are briefly discussed : Construction of acid tanks, live steam and submerged combustion heating, fume extraction, and treating spent pickling liquor.—J. G. W.

How and Why are Wires Pickled? F. Kohlhase. (*Draht*, 1953, **4,** Mar., 106–107). Alternative clearing methods are described and discussed, and some performance data are quoted.—S. G. W.

Stainless Strip Descaled and Brightened Continuously. L. H. Wilson. (*Steel*, 1953, **133,** Aug. 10, 96–98). The Du Pont sodium hydride descaling plant, installed at Sharon Steel Corp. is described. Three strands of stainless steel strip are annealed, descaled and electropickled in a single pass through the line. Descaling agent is 2% sodium hydride in molten caustic at 700° F. ; and it acts by chemically reducing the oxide scale without over pickling or pitting the base metal.

Hydraulic Descaling of Hot Steel. P. L. Fairfield. (*Iron Coal Trades Rev.*, 1953, **167,** July 17, 127–133 ; July 24, 205–212). The author discusses the techniques employed in the descaling of hot steel, giving details of the nozzles used to give a high-pressure spray, their positioning, the header design, and the water pressures and volumes required. The economics and suitability of the pumps and accumulators used are considered, and three typical hydraulic systems are described in detail. Disposal of the mill scale and the dirty-water return system are also mentioned.—G. F.

Cleaning and Preparation of Metals for Electroplating. V—Oil Spreading Rates. VI—Sensitivity of Degreasing Evaluation Tests. H. B. Linford and E. B. Saubestre. (*Plating*, 1953, **40,** Apr., 379–386 ; May, 489–496 ; June, 633–645). The spreading rates of several oils on steel surfaces have been determined. Polar oils spread less rapidly than non-polar mineral oils. Cleaning index values obtained previously by the water break and atomizer tests have been corrected for the effect of oil spreading. The atomizer test remains the more sensitive. The sensitivity of degreasing evaluation tests has been investigated when applied to steel panels, parts of which carry thin continuous films of oil. The sensitivity decreases in the order : atomizer, spray pattern, fluorescent dye, potassium ferricyanide paper, copper sulphate dip. Some extensions are made to the theory of wettability and the experimental results are correlated with experiments on Langmuir–Blodgett multi-layers and dropwise condensation phenomena.—J. P.

Report on Surface Preparation of Steels for Organic and Other Protective Coatings. N.A.C.E. Technical Practices Committee TP-6G. (*Corrosion*, 1953, **9,** May, 173–185). This second interim report describes many mechanical and chemical surface preparation processes, conditioners and pretreatments used commercially for organic and other coatings. The scope and limitations of each and the necessary safety measures are all mentioned, with notes on the surface condition to be expected from the treatment.—J. F. S.

Bright Pickling with 'Trinorm.' H. Anders. (*Werkstoffe u. Korrosion*, 1953, **4,** Apr., 122–123). The author describes the use of the proprietary solution 'Trinorm' to produce a bright steel surface. The articles are first descaled by an ordinary pickling process. The matt surface thus obtained is converted into a bright surface by immersion in the proprietary solution at 25–30° C., for up to 3 min.—J. C. H.

The Mechanical Descaling of Hot Rolled Strip by Blasting with Metallic Shot. M. Riemann and S. Schwandt. (*Stahl u. Eisen*, 1953, **73,** May 7, 630–636). The advantages of mechanical descaling are discussed and a centrifugal shot-blasting machine for descaling hot rolled steel strip is described. This machine takes up less space than a pickling line and its use eliminates all the disadvantages associated with acid pickling.

Hydro-Blast Equipment for Cleaning Castings. R. Chudzikiewicz. (*Przeglad Odlewnictwa*, 1953, **3,** 2, 46–50). [In Polish]. Hydro-blast equipment and its applications are reviewed.—V. G.

Combined Methods Aid Inspectors in Determining Shot Peening Coverage. H. H. Miller and P. H. Flynn. (*S.A.E. J.*, 1953, **61,** Feb., 29–33). Methods for assessing the percentage of surface struck by shot during a peening operation are described. The Straub method, using a microscope and planimeter, to measure the areas of the shot impressions is the most accurate, although time consuming. The surface replica method consists of taking a plastic replica of the peened surface and projecting through this transparency on to a screen. When used in conjunction with coverage standards this is an excellent method of control. Valentine's method involves peening a reference article made of low-carbon steel, which, on subsequent annealing, exhibits grain growth in the stressed regions below the surface.—P. M. C.

High-Pressure Jet Lapping in Metal Technology. H. Finkelnburg. (*Metall*, 1953, **7,** May, 330–334). Surface finishing by means of a high-pressure jet of a suspension of lapping abrasive in water is described. Performance in terms of

grain size, jet angle, distance between nozzle and workpiece, is analysed.—J. G. W.

Cleaning Precision Parts on a Jobbing Basis. E. F. Anderson. (*Metal Treating*, 1953, **4**, Mar.–Apr., 6, 7, 30). The wet blasting process for removing scale from precision parts is described. Abrasives in the range 80 to 2500 mesh are suspended as a slurry in a liquid media, and projected at the work by a compressed air gun. Tolerances of 0·0001 in. can be maintained if required.—P. M. C.

The Mechanical Surface Finishing of Metals. G. T. Colegate. (*Sheet Metal Ind.*, 1952, **29**, Jan., 71–78, 82 ; Feb., 163–172 ; Mar., 257–268 ; July, 645–650 ; Oct., 941–948 ; 1953, **20**, Jan., 5–17 ; Apr., 303–305, 307). Surface polish, its nature and measurement, are dealt with in Part 1. A comparison is made between mechanical and electrolytic polishing, and personnel and shop conditions are discussed. In Part 2, the effects of design and of previous treatment on the ease of polishing are outlined, and polishing lathes, techniques, and back-stand and automatic machines are described. Polishing operations and the various types of wheels, mops, and buffs are described and illustrated in Part 3. Part 4 deals with polishing compounds, binding media, and abrasives, and discusses their selection for particular uses. Part 5 deals with the polishing methods employed for steel, cast iron, stainless steel, and non-ferrous metals and alloys. Barrel processes and the mechanism of barrel finishing are discussed in Part 6, and the finishing of wire forms, and submerged abrasive burnishing are dealt with. Finally, Part 7 deals with wet blast cleaning, and sand and shot blasting of stainless steel.

It Will Pay You to Examine Surface Treatment Methods. A. G. Gray. (*Steel*, 1953, **132**, May 18, 92–96). Advances in surface treatment for improved plating and better corrosion protection are examined. A new electrolytic derusting and descaling process is described suitable for treating almost all types of iron alloys without attack on the base metal. Fluoboric acid is used in a new process for pickling metals not soluble in other acids. The application and properties of chromate coatings are dealt with.—D. L. C. P.

Metal Cleaning Process by Detrex Utilizes Ultrasonic Waves. (*Indust. Heating*, 1953, **20**, Apr., 737–740). **Ultrasonic Waves Used in Industrial Cleaning.** (*Steel Processing*, 1953, **39**, Apr., 166, 167). The development of ceramic transducers, which can focus and direct sound energy in a manner impossible with quartz crystals, has made possible the commercial ultrasonic degreasing equipment by the Detrex Corp. of Detroit. These ceramic transducers, which can be connected in series and arranged as desired, are immersed in a solvent such as trichlorethylene, and sound energy at 430,000 cycles/sec. is directed at the workpieces. Extreme agitation of the solvent occurs, and exceptional cleaning quality results.

How to Select Compounds for Barrel Finishing Metal. K. G. O. Pinke. (*Precision Met. Mold.*, 1953, **11**, Apr., 94–105, 119–126). Barrel finishing compounds are divided into five groups : (1) Abrasive ; (2) deburring ; (3) burnishing and colouring ; (4) degreasing ; and (5) scale and rust removal compounds. Details are given of the available compounds of each type. Simple methods by which the user can analyse them are given.—D. H.

Polishing and Barrel Finishing. L. Mable. (*Metal Ind.*, 1953, **82**, Mar. 13, 206, 207 ; Mar. 27, 244–246). The author considers from a practical viewpoint a number of problems which arise in a polishing department, and suggests means for their solution. The layout of barrel finishing shops, types of barrelling machines, and the classes of work for which they are suited are discussed.—P. M. C.

PROTECTIVE COATINGS

The Mechanization of Electroplating Processes. H. Silman. (*Bull. Inst. Met. Finish.*, 1953, **3**, Spring, 49–62). The author deals with automatic tanks for general plating. The advantages and disadvantages of mechanization are enumerated, and remedies for the latter suggested. Standardization of capital equipment is advocated, and electroplating must be regarded as an operation to be carried out on a machine placed in the production line like any other machine.—L. J. L.

Hydrogen Embrittlement of Steel during Electroplating. U. Trägårdh. (*IVA*, 1953, **24**, 2, 53–71). [In English]. Three spring steels (1·04, 1·07 and 0·70% C) were prepared for plating in one of the following ways : No pickling, anodic pickling in 10% H_2SO_4, and immersion in nitric acid. Loss in weight was then ascertained and a study made of hydrogen embrittlement of the steels (loss of bend number) as a function of : (1) The thickness of the zinc coating deposited by acid and alkaline baths ; (2) subsequent heat-treatment ; (3) current density ; and (4) prolonged storage periods.—G. G. K.

Ion-Exchange Materials in the Metallurgical Industries. T. R. E. Kressman. (*Sheet Metal Ind.*, 1953, **30**, May, 371–374). The article describes the use of ion-exchange materials for such purposes as water purification, recovery of plating solutions and rinse waters, and for the recovery and separation of gold and other metals from ores and waste liquors.

Metal Finishing As Applied to Industrial Heating and Ventilating Equipment. J. M. Sprague. (*Indust. Heating Eng.*, 1951, **13**, Dec., 355–357 ; 1952, **14**, Feb., 50–51 ; Apr., 102–105 ; May, 950–953 ; June, 179–182, 185 ; Oct., 297–299, 307 ; Nov., 344–347 ; Dec., 377–380 ; 1953, **15**, Jan., 23–25 ; Feb., 50–54).

Electroplating Steel Springs. (*Wire Prod.*, 1952, **2**, Dec., 9, 11). Recommendations of the Research Committee of the Coil Spring Federation, originally published in 1949, have been revised and are summarized under the headings of degreasing, descaling, electroplating, and recovery.—J. G. W.

Non-Destructive Measurement of the Thickness of Non-Metallic and Metallic Coatings. F. Förster. (*Metall*, 1953, **7**, May, 320–324). Suitable instruments for measuring the thickness of coatings on ferrous and non-ferrous metals and alloys are enumerated and their principles explained—J. G. W.

Electronic Measurement of Surface Coating Thickness. (*Product Finishing*, 1953, **6**, Mar., 47–50). The electrical circuit of an apparatus for measuring the thickness of non-conducting, non-magnetic coatings on iron and steel surfaces is described. It measures, in terms of thickness, the change in impedence of a gauge coil as the distance between the yoke of its steel core and the basis metal is varied.—J. P.

Determination of Zinc and Tin Coatings with Hydrochloric Acid Containing Antimony Trichloride. G. Schikorr. (*Metall*, 1953, **7**, May, 337–341). Sources of error in the determination of the thickness of zinc and tin coatings by means of hydrochloric acid with antimony trichloride are examined, and it is recommended that the reaction should last not longer than 30 sec. for zinc determinations ; for tin determinations the British Standard solution is recommended.—J. G. W.

Chromium Plating with or without Undercoats. J. J. Dale. (*Plating Notes*, 1952, **4**, June, 97–99). The corrosion resistance of chromium electrodeposits on steel with and without undercoats of nickel, copper, zinc or brass are discussed.—J. P.

Chromium Diffusion for Corrosion and Abrasion Resistance. F. M. Burt. (*Metal Finishing*, 1953, **51**, Apr., 72–75, 84). A process, in which steel articles are packed in a chromizing compound and heated to produce a diffused coating, is described but no particulars are given of the composition of the compound. The properties of the coatings and the coated articles are discussed and illustrated.—J. P.

Investigation of Diffusion of Chromium in Iron-Chromium Alloys Containing Third Elements. S. Gertsriken and I. Dekhtyar. (*Zhurnal Tekhnicheskoi Fiziki*, 1950, **20**, 8, 1005–1014). The diffusion of chromium in Fe–Cr alloys with additions of one of the following elements, nickel, beryllium, niobium, tungsten, silicon, titanium, and tin, was studied in the temperature range 950–1070° C. The dependence of the energy and entropy of activation on the valency and atomic number of the added third element was established. A formula for calculating the time to homogenize to a given degree the above iron-base ternary alloys is proposed.—V. G.

Some Properties and Applications of Hard Chromium Plating C. J. Cocks. (*Inst. Australian Found.* : Victorian Div., 1952 Convention, 175–184). The history of hard chromium plating is briefly described. The methods of plating, grinding and finishing ; properties (hardness, coefficient of friction, adhesion, strength and ductility) ; and the application to a wide range of articles are then discussed.—P. M. C.

Practical Experiences with Chromium without Nickel Undercoats. D. Cam. (*Plating Notes*, 1952, **4**, June, 100–101). Electrodeposits of chromium from a special proprietary ' cold ' bath have good resistance to corrosion when plated directly on brass or zinc base die castings or on steel with an undercoat of zinc. Methods of working are described.—J. P.

Notes on the Peeling of Nickel Deposits. E. T. Richards. (*Metal Finishing*, 1953, **51**, Apr., 64–67 ; May, 60–65). Factors which may induce peeling of nickel deposits are discussed. These relate to the surface of the basis metal and

its preparation, the conditions of deposition, impurities in the plating bath, and after-treatment of the deposit. A table of symptoms, causes, and remedies is given.—J. P.

Galvanizing: Auxilliary Equipment. A. Gordet. (*Mét. Constr. Mécan.*, 1953, **85,** Jan., 55–57). A short description of equipment used in galvanizing practice, including a pump for liquid zinc and skimming ladles, is presented.—B. G. B.

The Behaviour of Fluxes on Galvanizing Baths Containing Aluminium. H. Bablik, F. Götzl, and R. Kukaczka. (*Werkstoffe u. Korrosion*, 1953, **4,** Apr., 121–122). It is impracticable to use a zinc chloride flux on the surface of a galvanizing bath if the molten zinc contains an addition of aluminium because the aluminium displaces the zinc from the chloride and is lost as volatile aluminium chloride. Attempts to stabilize the flux by adding cryolite to it failed.—J. C. H.

Electrolytic Zinc Plating. J. Liger. (*Mét. Constr. Mécan.*, 1953, **85,** Apr., 301–305). A short description is given of the electrolytic zinc plating process. The effects obtained with alkaline and acid baths are discussed and the necessity for efficient cleaning of the articles before plating is stressed.

The Bending Capacity of Zinc Coatings. H. Bablik, J. Krystof, F. Götzl, and R. Kukaczka. (*Metall*, 1953, **7,** May, 313–319). The authors report investigations of the ductility of galvanized coatings, from which they conclude that in the absence of zinc–iron alloy the satisfactory performance in bending and other plastic working operations is accounted for by slip and twinning in the pure zinc. When the zinc–iron alloy is present, coatings behave differently in tension and in compression. In tension, cracks are not accompanied by flakin gowing to adhesion between the iron–zinc alloy and the base ; in compression, however, flaking is inevitable owing to the brittleness of the alloy.—J. G. W.

Bright Zinc Plating. R. D. Taylor. (*Plating Notes*, 1952, **4,** June, 74–83). The methods, including compositions of solutions, by which steel may be plated with zinc and subsequently treated to produce a coating with maximum corrosion resistance and best appearance are described.—J. P.

Practical Experiences with Bright Zinc Plating. A. Chesterfield. (*Plating Notes*, 1952, **4,** June, 84–86). Information is given for the practical plater on equipment, costs, and composition and control of bright zinc plating and bright dipping solutions.—J. P.

The Problem of Weak Soldered Joints in Tinplate Containers. W. E. Hoare and J. P. Gustin. (*Rev. Mét.*, 1953, **50,** May, 301–310). Weak joints are generally caused by a combination of minor factors of fabrication, but the fault may be with the tinplate in certain cases. A study of a large number of containers, sound and unsound, shows that faults may be related to large variations in the thickness of the tin layer, or to contamination of the base steel.—A. G.

Hot Tinning. A. Gordet. (*Mét. Constr. Mécan.*, 1953, **85,** Feb., 131–134). The hot-dip process for the tinning of steel is reviewed. The tinning capacity of different types of steel is discussed and the reasons for certain types of steel being difficult to plate are considered.—B. G. B.

Hot Dip Tinning. G. Haas and A. Gordet. (*Mét. Constr. Mécan.*, 1953, **85,** Mar., 213–215 ; May 401–403). The preparation of articles before tinning is discussed and the composition of a number of cleaning baths is considered.—B. G. B.

Spray Metallizing. A. Stagmo. (*Tec. e Indust.*, 1952, **30,** Oct., 1048–1050). [In Spanish]. Oxy-acetylene metal-spraying pistols fed by wire and electrically driven, and pistols fed with metal powder, are described and the properties of sprayed coatings are discussed.—R. S.

Immersion "Brass" Coatings on Steel. H. W. Richter. (*Metal Finishing*, 1953, **51,** May, 66, 67, 76). Methods are given for the preparation, use and control of solutions for depositing, by chemical displacement, copper-tin alloys on steel wire.—J. P.

Control of Phosphating Solutions. G. Gabrielson. (*Metal Finishing*, 1953, **51,** Apr., 76–78). The amounts of phosphates and nitrates in a phosphating bath are determined by titration of the acids produced when a portion of the bath is passed through a column of Amberlite IR–120 cation exchange resin.—J. P.

Colourless Lacquers. J. Towner. (*Plating Notes*, 1952, **4,** June, 87–90). The properties required in a lacquer for protecting electrodeposited chromium or zinc coatings against corrosive agents are discussed and suitable materials and methods of application are described.—J. P.

Production Methods in the Enamelling Shop. H. M. Hibberd. (Inst. Vitreous Enamellers : *Sheet Metal Ind.*, 1953, **30,** Mar., 233–235). Very brief details are given of the production of castings and subsequent coating, drying, fusing, and coating inspection methods employed at the author's works.—P. M. C.

The Adhesion of Magnesite Powders to a Solid Surface. E. Cremer and F. Conrad. (*Radex Rundschau*, 1952, No. 1, Feb. 3–6). The adhesion of mixtures of magnesite powders and the adhesion and coefficient of friction of magnesite at different stages of decarbonization were investigated. The effects of firing temperature and grain size are considered. Adhesive force and adhesive tension of partly dissociated magnesite are found to be much reduced and independent of grain size.—E. C.

POWDER METALLURGY

Control in Powder Metallurgy. H. W. Greenwood. (*Metal Ind.*, 1953, **82,** June 5, 461–462). The adverse effect of oxidation of metal powders on die life and sintering pressure is discussed, and the need for oxygen-free storage is emphasized. The poor flow factor of very fine powders, and improvements therein by additions such as wax and dissolved plastics are considered. The use of copper and copper alloys as infiltrating media for iron parts is discussed ; this is a technique which may be used to enhance density and physical properties very much above the usual figures for iron.—P. M. C.

Altering the Sintering Properties of Metal Powders by Surface Treatment. G. Naeser and H. Burmeister. (*Arch. Eisenhüttenwesen*, 1953, **24,** May–June, 251–255). Attempts have been made to improve the mechanical properties of sintered iron compacts by pretreating with materials (oxides, chlorides, acetates, etc.) which can be reduced to metals in hydrogen at low temperatures. It was expected that the metal so formed would be more reactive and would then sinter more readily. Little success was achieved. However, treating the iron powder with ammonium phosphate and then reducing at 750° C. in hydrogen produced a phosphide powder which did give compacts of much greater strength than those made from untreated powder. This was because, as the phosphorus diffused into the iron at the sintering temperature of 1100° C., the surface of the particles eventually reached the Fe-P eutectic composition (m.p. 1060° C.). Fusion took place and welded the particles, but as the phosphorus diffused further into the iron the weld soldified. This treatment is of great use for welding sintered iron to solid iron or steel or to other sintered iron. The two surfaces to be joined are treated with phosphate, placed in contact and heated in hydrogen to 1100° C.—J. P.

Hard-Metal Alloys of High Corrosion and Oxidation Resistance. J. Hinnüber and O. Rüdiger. (*Arch. Eisenhüttenwesen*, 1953, **24,** May–June, 267–274). The mechanical and physical properties of a chromium-carbide/nickel alloy (12% Ni) are reported. The material has good corrosion resistance and a high coefficient of thermal expansion which makes it appear suitable for use in facing steel. Investigations have shown that additions of chromium, tungsten and tantalum carbides to titanium-carbide/cobalt alloys lead to an improvement in oxidation resistance whereas vanadium, molybdenum and zirconium carbides are detrimental.—J. P.

Phosphorus Alloyed Sintered Steel. F. Eisenkolb. (*Arch. Eisenhüttenwesen*, 1953, **24,** May–June, 257–266). Experiments have been carried out in which iron powder has been treated with powdered ferrophosphorus, pure phosphorus, or compounds which are reduced to phosphorus when heated in in reducing gases, and the resulting material being pressed and sintered. Good mechanical properties are thus obtained and pore volume is much reduced as compared with that of plain sintered iron. The cause of the improvement is the formation during sintering of liquid Fe–P eutectic which welds the particles together, the weld subsequently solidifying when the phosphorus diffuses further into the iron. The process should prove of commercial value, but care must be taken to allow for the abnormal shrinkage which occurs. The optimum phosphorus content is 0·8%.—J. P.

Density Determination of Porous Metal Parts. W. M. Schwarzkopf. (*Powder Met. Bull.*, 1953, **6,** Feb., 134–135). The replacement of paraffin oil by silicones as water-proofing agents eliminates one routine weighing, since the weight increase due to impregnation is below the required accuracy

of weighing. The amount of carbon introduced can be neglected if carbon determinations are needed. Cost is not excessive, since very little silicone per part is used.—K. E. J.

Impregnation of Powder Metallurgy Parts Improves Corrosion Resistance. W. N. Pratt. (*Steel*, 1953, **133,** July 13, 122–123). A process for filling the pores of sintered metal is described ; this enables the parts to be cleaned and plated. The impregnant is a thermosetting polyester styrene copolymer.—D. L. C. P.

Can Sinterings Be Used in Automotive Hydraulic Pumps? Tests Show They Can. (*Precision Met. Mold.*, 1953, **11,** May, 34–36). Performance characteristics of iron–copper sinterings intended for use in hydraulic pumps have been studied.—D. H.

The Manufacture of Self-Lubricating Bearings. Sintering in the Presence of a Liquid Phase. P. Laurent and M. Eudier. (*Rev. Mét.*, 1953, **50,** June, 382–388). Difficulties due to a liquid phase causing distortion of the bearing are discussed. A study of the amount of liquid formed during sintering as a function of the temperature and the rate of diffusion for copper–tin and iron–copper alloys enables the optimum thermal treatment and grain size of the powder to be determined.—A. G.

PROPERTIES AND TESTS

A Method of Obtaining Shear Stress-Strain Graphs by Interpretation of Moment-Twist Data. P. H. Kaar. (*Trans. Amer. Soc. Mech. Eng.*, 1953, **75,** May, 521–523). A method is described whereby shear stress/strain curves for truck axles can be readily obtained from moment twist data.—D. H.

The Influence of the Rate of Deformation on the Tensile Properties of Some Plain Carbon Sheet Steels. J. Winlock. (*Trans. Amer. Inst. Min. Met. Eng.*, 1953, **197;** *J. Met.*, 1953, **5,** June, 797–803 ; *Iron Coal Trades Rev.*, 1953, **167,** July 24, 200–202). The author discusses the behaviour of steel at the yield point and describes experiments to show the influence of deformation rate on the tensile properties of plain carbon sheet steels with carbon contents ranging from 0·06% to 1·03%. With increasing deformation rates, it is shown that all load-sustaining properties increase and all percentage elongations either remain constant or increase, whilst with increasing amounts of free ferrite, load-sustaining properties increase and percentage elongations decrease. The experiments indicate that the plastic behaviour of steel imposes no limitations on new methods of deep drawing with much higher deformation rates.—G. F.

New Tests on Steel Suggest Error in Poisson's Ratio. W. D. Manley. (*Iron Age*, 1953, **171,** Apr. 23, 148–150). Three different types of test employing strain gauges have shown that at stresses up to 18,000 lb./sq. in. Poisson's ratio for hot rolled steel is between 0·23 and 0·25, and not 0·29 to 0·33 as generally accepted. It is not known whether this value will apply at higher stresses.—A. M. F.

Necking and Rupture of Rods Subjected to Constant Tensile Loads. N. J. Hoff. (*J. Appl. Mech.*, 1953, **20,** Mar., 105–108). A one-dimensional theory of the behaviour of a non-linear viscoelastic bar subjected to a constant tensile load is developed with the aid of a creep law considering secondary creep only. The theoretical value of the time at which the bar ruptures, and the shape calculated for the necked portion of the bar are in satisfactory agreement with the results of experiments on aluminium alloys. The rupture time tests were carried out on thin sheet specimens.—J. R. P.

Elastic Waves Created During Tensile Fracture. J. Miklowitz. (*J. Appl. Mech.*, 1953, **20,** Mar., 122–130). In tests with brittle materials, fractures were produced at two different cross sections of the specimens when the rupture load was reached. The second fracture is probably caused by the destructive action of the elastic strain waves created during the first fracture. The problem was reduced to that of a vibrating cantilever beam with time-dependent boundary conditions. Two types of wave are shown to exist, a longitudinal unloading wave (compression) and a group of flexural strain waves caused by the moment that develops at the initial fracture section. The methods of operational mathematics and the electric-analogue computor have been employed in the analytical study. Fracture data are given on high-speed steel specimens.—J. R. P.

A Machine for Tensile Testing at Controlled Temperatures and Constant True Strain Rates. E. L. Bartholomew, jun., K. J. Krystyan, D. A. J. Millar, and J. Wulff. (*Rev. Sci. Instruments*, 1953, **24,** Mar., 196–202). To obtain a constant true strain rate in a heated tensile test bar, an enlarged shadow of the bar was so adjusted that one edge corresponded with a slit, which moved at a rate equal to the required lateral movement of the shadow. Any light entering the slit owing to incorrect lateral contraction of the shadow generated a signal, which corrected the speed of the crosshead causing the strain. The mechanism of this device is described in detail.—L. D. H.

Testing Machines for the Measurement of Spring Force. O. Göttfert. (*Draht*, 1953, **3,** Apr., 123–129 ; May, 179–183). The principles of design of spring testing machines are explained in detail in the first part of the article, and 19 different machines of German manufacture are illustrated and briefly described in the second part.—J. G. W.

The Significance of Notched Bar Tests. W. J. Kaufman. (*Lastechn*, 1953, **19,** June, 78–82 ; July, 94–101). [In Dutch]. The author describes briefly some notable failures of welded structures outlining what happens in the crystal lattices when tensile and shear stresses are applied. The current testing methods are described. It is concluded that notched bar tests give results unsuitable for incorporation in calculations merely classifying the materials in the order of susceptibility to fracture. The tests indicate that, particularly at low temperatures, the risk of fracture is greatest. Accumulation of welds in complicated structures should be avoided and stresses and strains relieved by annealing.—F. R. H.

The Charpy Impact Machine and Procedure for Inspection and Testing Charpy V-Notch Impact Specimens. D. E. Driscoll. (*Amer. Soc. Test. Mat. Bull.*, 1953, July, 60–64). The effects which variables in specimen shape and testing procedures may produce on the results of notched bar impact tests, are considered. The procedure, used at the Watertown Arsenal Laboratory, U.S.A., when inspecting and testing standard V-notch Charpy impact specimens is described.

Propagation of Brittle Fracture in Steel. T. S. Robertson. (*J. Iron Steel Inst.*, 1953, **175,** Dec., 361–374). [This issue].

Deformation Twinning in Charpy V-Notch Specimens of Ingot Iron. G. W. Geil and N. L. Carwile. (*Welding J.*, 1953, **32,** June, 273s–282s). A metallographic study was made of deformation twinning in hot-rolled ingot iron deformed rapidly by impact at temperatures ranging from −196° to +100° C. As twins were observed in all of the specimens tested in this temperature range, deformation twinning in ingot iron is not restricted to a brittle behaviour or deformation resulting in cleavage fractures. Twins were developed during the initial stages of plastic deformation and they apparently increased in breadth with increase in the strain of the specimens. The presence of many bent and severely distorted twins indicates that the twinned region of a grain is not brittle, and that deformation twinning is not the cause of low-temperature embrittlement of ingot iron.—U. E.

Problems in Experimental Stress Analysis. H. Le Boiteux. (*Métaux-Corrosion-Indust.*, 1953, **28,** June, 239–243). The mathematical interpretation of the optical patterns produced when transparent models, illuminated with polarized light, are subjected to stress, is discussed.—B. G. B.

Thermo-Electric Phenomena in Stressed Metals. W. Späth. (*Metall*, 1953, **7,** June, 430–432). The author attempts an explanation of thermo-electric phenomena observed in stressed metals. It is shown that thermo-electrically active layers can arise in metals from a variety of causes. Graphite in cast iron and grain-boundary precipitation, for example, can set up thermo-electric currents of considerable density but very short duration.—R. A. R.

Determination of the Stresses in Elastic Plates by Means of Photoelasticity. R. Kuhn. (*Forsch. Ingenieurwesens*, 1952, **18B,** 3, 72–80). The ' freezing ' method of photo-elastic stress measurement was used to determine the three-dimensional stress distribution in square plates (*a*) supported horizontally at two diagonally opposite corners and loaded vertically at the other corners ; and (*b*) freely supported all round the edge and loaded with a point load in the centre.—H. R. M.

Stress-Strain Relation in Shear from Twisting Test of Annulus. W. Ramberg and J. A. Miller. (*J. Res. Nat. Bur. Stand.*, 1953, **50,** Feb., 125–129). It is shown that the stress-strain relation in shear of isotropic thin sheet can be determined from a test of an annular specimen. The annulus must be clamped uniformly along the inner and outer edge, and the relative twist of two circles concentric with the edges must

be measured. The shear strain at the inner circle can be computed from the shear strain at the outer circle and the slope of the torque-twist curve.—J. C. B.

Observations on the Fatigue Strength of Uniformly Lead Coated Steel Sheet. G. Hillen and W. Hofmann. (*Z. Metallkunde*, 1953, **44,** Apr., 131–132). Steel strip coated with lead was subjected to alternating bend tests, to investigate the effect of the lead composition on the incidence of cracking; the experiments were duplicated at room temperature and at 100° C. The onset and progress of cracking were followed by measuring variations in the electrical resistance. At 100° C., fine lead proved most resistant to cracking.—L. D. H.

The Effect of Stress Concentrations on the Time-Resistance of Materials. G. Sachs, W. F. Brown, jun., and D. P. Newman. (*Z. Metallkunde*, 1953, **44,** June, 233–239). After prestressing at just below the fatigue limit, specimens are capable of withstanding fatigue stresses above the fatigue limit for some time without fracture ; this property (*Zeitstandfestigkeit* = time-resistance) was found to depend upon both the temperature and duration. The relationships are remarkably similar to those relating to the tensile strength of age-hardening alloys. No limit of plasticity, representing the value below which a bar becomes notch sensitive, can be given.

Physical Phenomena in Fatigue Testing. U. Dehlinger. (*Z. Metallkunde*, 1953, **44,** June, 240–242). Results of investigations on the effect of external conditions, particularly the effect of prestressing below the fatigue limit, on the fatigue strength of single crystals and polycrystalline materials are critically examined. It is concluded that the cause of the disorder is an athermic recovery process in the crystals brought about by repeated slip.—R. A. R.

Fatigue Strength and Electroplating. R. H. Warring. (*Mech. World*, 1953, **133,** May, 206–208). The author deals briefly with the effect of compressive and tensile surface stresses on the fatigue limit of a component. Methods of overcoming the tensile stresses in electroplate and thus increasing the fatigue limit of a plated component are reviewed.—D. H.

The Dependence of Indentation Hardness on Load, and a Proposed New Definition. P. Grodzinski. (*Schweiz. Arch. Wiss. Techn.*, 1952, **18,** Sept., 282–292). In the field of microhardness testing, it is unsatisfactory to define hardness either as a stress or as a load per unit volume of indentation, because both these depend on the load. Since Meyers' empirical Law is valid for many materials and indenting tools, it is proposed to define hardness by the load required to give an impression with unit value of depth or some characteristic length. At least two measurements at different loads are required to determine this. Using a hardness tester in which load increases continuously, the relation between the newly defined and the orthodox values of hardness is explored.

Some Advantages of the Tukon Microhardness Tester in Metallography. D. Gualandi. (*Alluminio*, 1952, **21,** 5, 463–471). [In Italian].

Light Load Hardness Testers. K. Walz. (*Draht*, 1953, **4,** May, 176–178). Some German and Austrian microhardness testing machines are described.—J. G. W.

Exploiting the Principle of Raising the Elastic Limit in Steels by Work Hardening and Artificial Ageing in the Construction of High-Pressure Pipes. U. Bellometti. (*Costruzioni Met.*, 1953, **5,** Mar.–Apr., 33–42 ; May–June, 33–38). [In Italian]. The author describes how work hardening and artificial ageing of steels is used on an industrial scale to raise the initial elastic limit of steels without producing brittleness. This ensures considerable economy of metal and cost while improving the quality of the tube. The present trend in France is to use work-hardened pipes which are subsequently artificially aged by heat-treatment. The pipes can be tested while the work-hardening is in progress because both operations are performed by applying hydraulic pressure, which is measured.—M. D. J. B.

On the Looseness of Wear Fragments. E. Rabinowicz. (*J. App. Phys.*, 1953, **24,** Mar., 367). Friction experiments between smooth surfaces containing radioactive materials have shown that wear fragments are generally welded to the surface even when the temperature increase is negligible.

Permanent Magnets and Their Application in Practice. H. Fahlenbrach. (*Metall*, 1953, **7,** June, 413–421). The author reviews current theories concerning permanent magnets, summarizes the history of modern magnetic materials, and discusses their application making comments on design and calculation.—J. G. W.

Behavior of Magnetic Materials. R. M. Bozorth. (*Amer. J. Phys.*, 1953, **21,** Apr., 260–266). In this review of recent work, the atomic theory of ferromagnetism and the domain theory of magnetization are applied to new materials such as ferrites, particularly in defining the relation between atomic structure and magnetization at saturation.—J. O. L.

Ultrasonic Testing by the Transmission and Pulse Echo Methods. H. Krainer and E. Krainer. (*Arch. Eisenhüttenwesen*, 1953, **24,** May–June, 229–236). The ultrasonic testing equipment of the Austrian firm Elektrofona is adopted for both of the above methods. A comparison of the two methods shows that the pulse echo is superior; the transmission method is suitable only for flat products. Steel bars over 2 in. in diameter and heavy forgings have been successfully tested by the pulse echo method, which may also be used for detecting fatigue cracks. The dependence of the transmissibility of a material on grain size has been investigated on a 17% Cr steel. Calculation of the attenuation coefficient gives indication of the greatest thickness that can be measured for a given grain size ; alternatively, the attenuation provides information on grain size. Estimation of the thickness of a hardened layer as produced by cold rolling, is possible. Tests on heavy forgings have shown up segregations, flakes, and slag stringers. Microcavities and regions of particularly coarse grain have been detected in cast steel rings.—J. P.

Ultrasonic Testing Instruments. R. H. Warring. (*Machinery Lloyd*, 1953, **25,** Aug. 8, 107–111). The author discusses the theory relating to the measurement of metal thicknesses by means of ultrasonic waves. The source of these waves is a vibrating quartz crystal operated below the natural frequency of the crystal itself, and driven by an electric oscillator with frequency modulator control. This method may be used to measure steel thicknesses from $\frac{1}{16}$ to 12 in. and can be applied to the measurement of interior corrosion pitting rates.—J. C. B.

Ultrasonic Equipment for Detecting Flaws in Rails. (*Engineer*, 1953, **196,** July 3, 15 ; *Engineering*, 1953, **176,** July 3, 11 ; *Railway Gaz.*, 1953, **99,** July 10, 45–46). A description is given of the Audigage rail flaw detector developed by The Branson Instruments Inc. of Stamford, Conn., U.S.A. The set consists of a small battery-operated ultrasonic frequency generator and receiver, carried in an 11½-lb. pack on the operator's back, a crystal in a holder on the end of a long handle and headphones. The crystal is applied to the rail head and the presence of a crack is indicated by a lowering of the continuous tone produced by a perfect rail.—M. D. J. B.

Castings and Ultrasonic Testing. (*Foundry Trade J.*, 1953, **94,** May 28, 611–612). The author summarizes the present position with regard to ultrasonic testing which shows promise for some classes of work. The difficulties experienced in the application of this method to castings are dicussed. The limitations imposed by the type of apparatus required and necessity for highly skilled operators are emphasized.—L. E. W.

Ultrasonic Vibrations and Their Metallurgical Applications. K. F. Alder. (Australian Inst. Metals : *Australasian Eng.*, 1952, Dec. 8, 53–59). The methods of generating ultrasonic vibrations are discussed, particular emphasis being placed on the phenomenon of magnetostriction and on piezo-electric generators. A review of metallurgical applications is given, attention being concentrated mainly on the grain refinement of castings. (28 references).—P. M. C.

Construction and Operation of Ultrasonic Testing Equipment. I. H. Schmauch. (*Metall*, 1953, **7,** Apr., 234–241). The physical principles underlying ultrasonic testing are explained and the testing equipment is described.—J. G. W.

Measurement of Ultrasonic Attenuation in Metals by the Pulse Method. S. Tanaka and T. Anzai. (*Sci. Rep. Res. Inst. Tôhuku Univ.*, 1952, **A4,** Dec., 643–650). [In English]. A method for measuring attenuation in some common metals is described with results obtained in the 500 kilocycles/sec. to 6 megacycles/sec. range by pulse techniques. Many corrections were introduced to obtain accuracy. Attenuation constants were determined for mild steel, cast iron, aluminium and copper.—K. E. J.

Magnetic and Fluorescent Investigation of Materials and Parts. A. van 'T Hoen. (*Metalen*, 1953, **8,** Jan., 45, 13–16). [In Dutch]. Some well-known characteristics of the magnetic and magnetic fluorescent non-destructive testing methods are described.—R. S.

Reduction of Exposure Time in Gamma Radiography. J. J. Hirschfield and D. T. O'Connor. (*Non-Destructive Test.*, 1953, **11**, Mar., 28–33). The authors show that fast films and filters used in conjunction with chemical intensifying screens will yield radiographs comparable in quality with those made with lead screens and fine grained film in 5% of the time. This technique, coupled with a selection of optimum film-source distance, should increase the efficiency of any radiographic inspection undertaken with radioisotopes.—P. M. C.

Lowered Production Costs Through the Use of Dy/Chek or Spek/Chek. G. Rice. (*Non-Destructive Test.*, 1953, **11**, Mar., 16–22). The use of liquid penetrating dyes for the detection of cracks, porosity and seams is described, and several examples of the methods' application are discussed and illustrated.—P. M. C.

Economic Factors of Nondestructive Testing. W. E. Thomas. (Soc. for Non-Destructive Testing : *Non-Destructive Test.*, 1953, **11**, Mar., 9–12). This is a general appraisal of the need for managements to assess the limitations, uses, and costs of non-destructive methods of testing and quality control.—P. M. C.

A Permanent-Magnet Crack Detector. J. W. Walley. (*Engineering*, 1953, **176**, July 3, 5). This article describes a new design of magnetic crack detector developed by Metropolitan Vickers Electrical Co., Ltd., The detector is intended for the rapid handling of components to be examined for transverse faults. Use is made of a permanent magnet for magnetizing the component instead of the more conventional electric current windings.—M. D. J. B.

Non-Destructive Testing of Materials. A. Neth. (*Österr. Masch. Elektrowirtschaft*, 1952, **7**, Nov., 514–517). A brief account is given of the symposium on non-destructive testing held at Leoben on 30–31 Oct., 1952, by the Verein Eisenhütte Österreich. The subjects dealt with included X-ray, gamma-ray, beta-ray, ultrasonic, magnetic, and electric methods of testing, surface testing, and strain measurement.—H. R. M.

A New Recording Method for Non-Destructive Testing of Surface Defects. W. Stauffer and A. Keller. (*Schweiz. Arch. Wiss. Techn.*, 1952, **18**, May, 137–148). Records can be obtained of surface defects shown up by either the magnetic powder method or by the indicating liquid (fluorescent liquid or dye) method. A solution of a lacquer is applied by dipping, pouring on, or spraying, and after the solvent has evaporated, the lacquer skin is removed. It carries with it the absorbed pattern of the marking powder or liquid, giving a permanent record of the defects. Examples are illustrated.—H. R. M.

A Non-Destructive Test for Thin Shells. J. C. New. (*J. Appl. Mech.*, 1953, **20**, Mar., 48–50). The differential pressure test is a non-destructive, experimental technique for determining incipient buckling pressures of thin shells subjected to external pressure. The internal volume of the shell is filled with a compressive fluid to control the magnitude and rate of shell deformation. The incipient buckling pressure is detected by noting the point at which the difference in internal and external pressure becomes constant. Experimental verification of the technique and its non-destructive aspect is presented. Applications and limitations of the test are discussed.—J. R. P.

Industrial Evaluation of Search Coil Flaw Detection Techniques. C. H. Hastings and G. A. Darcy. (*Non-Destructive Test.*, 1953, **11**, May, 24–29). The induction and A.C. bridge flaw detection techniques, are discussed. Reference is made to a magnetic recording 'boroscope' designed for the automatic, non-destructive inspection of the bores of gun barrels. The equipment comprises a magnetic tape recording type of search coil, a signal amplifier, and a facsimile type recorder. A maplike presentation of the bore surface flaws is obtained. Tests are described which were undertaken to compare the performance of this equipment with the usual optical 'boroscope.' The automatic recorder is more sensitive and detects smaller cracks than the optical method.—P. M. C.

Aspects of Nuclear Fission of Interest to Foundrymen and Metallurgists. E. W. Colbeck. (*Foundry Trade J.*, 1953, **94**, June 18, 697–706). The aspects discussed include the use of radioisotopes in radiography, the use of radioactive tracers both in metallurgical processes and in physical metallurgy, and the metallurgical problems involved in the production of power from nuclear reactors.—B. C. W.

The Applications of Radioelements in Metallurgy. A. Kohn. (SIM : Documentation Métallurgique, 1953, **13**, 9–30). The properties of the common radioactive isotopes are tabulated and methods of measuring activity described. The work of various investigators who have used radioisotopes in metallurgical studies is outlined. The technique has been employed in the laboratory to study segregation and diffusion and in chemical analysis, and on the industrial scale in coke-oven and blast-furnace investigations. (70 references).

Thermal Conductivity Data Presented for Various Metals and Alloys up to 900° C. L. Silverman. (*J. Met.*, 1953, **5**, May, Section 1, 631–632). Curves relating thermal conductivity and temperature are shown for 18 metals and alloys including stainless steel and nickel–iron alloys with 52% and 42% of nickel) used in the electron tube industry, conductivities being measured by a modification of the Van Dusen and Shelton comparative method. Iron and titanium are exceptions in that their conductivities decrease with increasing temperature.—G. F.

The Thermal Conductivity of Metals at Low Temperatures. J. L. Olsen and H. M. Rosenberg (*Advances in Physics*, 1953, **2**, Jan., 28–66). The temperature variation of electronic conduction in normal metals, and the effects of impurities, magnetic fields and crystalline anistropy are discussed. In discussing alloys, the lattice conduction is also considered. The effects of superconductivity and the behaviour of thermal conductivity below 1° K. are dealt with. References are given to results for some steel alloys. Experimental techniques are outlined. (50 references).—K. E. J.

Equipment for Compression-Creep Tests at High Temperatures. A. E. Johnson and N. E. Frost. (*Engineering*, 1953, **176**, July 3, 28–29). These authors describe a compressive-creep machine designed at the National Physical Laboratory and developed in the Fulmer Research Institute. The machine is capable of carrying out compressive-creep tests at high temperatures with a precision comparable to that obtained for tensile creep.—M. D. J. B.

Creep Testing by a Cantilever Bending Method. G. T. Harris and H. C. Child. (*Métaux-Corrosion-Indust.*, 1953, **28**, Apr., 152–158). Creep testing by the cantilever bending method is described. The method is shown to have advantages over tensile testing at high temperatures and to reduce the time required to prepare the specimen. There is good correlation between the results obtained by this method and those of conventional tests.—B. G. B.

How to Solve Fabricating Problems of High-Temperature Alloys. H. Brown. (*Iron Age*, 1953, **171**, Apr. 16, 121–125). Some of the difficulties experienced are discussed. Defects in these alloys are much more critical than in standard steels, notch sensitivity and rapid work hardening cause trouble unless parts are 'deburred' before forming or welding. Most alloys will readily pick up carbon and zinc, and care must be exercised in keeping them free from these elements. Carbide networks in the stainless grades cause trouble in severe forming but this can be overcome by proper mill processing and heat-treatment.—A. M. F.

Simple Devices for Approximating Constant Stress During Tensile Creep Tests. R. L. Fullman, R. P. Carreker, jun., and J. C. Fisher. (*Trans. Amer. Inst. Min. Met. Eng.*, 1953, **197**: *J. Met.*, 1953, **5**, May, 657–659). During tensile creep testing under constant load, stress increases in proportion to elongation. The authors show that proper choice of dimensions of a simple loading beam permits maintenance of very nearly constant stress during testing of polycrystalline material, and of nearly constant resolved shear stress during testing of single crystals.—G. F.

Creep of High-Tensile Steel Wire. N. W. B. Clarke and F. Walley. (*Proc. Inst. Civ. Eng.*, 1953, **2**, Mar., 107–135). When high-tensile steel is used at stresses high in relation to its ultimate strength, as in pre-stressed concrete, creep at normal temperatures may be important. The authors describe work carried out to determine it quantitativity. The method of testing, apparatus, procedure and results are described. Stress loss is shown to be a function of the ratio of the applied stress to the ultimate stress.—L. J. L.

Comparisons at Elevated Temperatures of Some Commercial Grades of Ferritic Cast Steels. H. W. Wyatt, J. W. Bolton, and M. L. Steinbuch. (*Trans. Amer. Soc. Mech. Eng.*, 1953, **75**, Feb., 289–300). The paper presents some comparisons of high temperature test data on cast steels. The tests show that, at the temperatures under consideration, the nominal 1% molybdenum grades W.C.5 and W.C.9 are higher in creep strength than the nominal 0·5% molybdenum grades W.C.4 and W.C.6.—D. H.

Steels For High Temperature Service. P. Payson. (Amer. Soc. Mech. Eng. : *Steel Processing*, 1953, **39**, Apr., 168–174). An elementary outline of the phenomenon of metallic creep at elevated temperatures is given, and the methods of measuring and presenting creep data are discussed. A general review follows of the creep properties and high temperature applications of many types of steel.—P. M. C.

Steels for Steam Power Plant. A. M. Sage. (*Inst. Mech. Eng., Preprint*, 1953, Mar. 13). The author reviews the work carried out for the Steels for High Temperature Committee of the British Electrical and Allied Industries Res. Assoc. between 1930 and 1952. The study of the effects of creep properties in different steels led to the adoption of Cr–Mo, Cr–Mo–Si, and to a less extent, Mo–V steel for high-temperature components such as superheater tubes, steam pipes, and superheater headers for plant operating at above 900° F. Results and methods of creep testing are compared, and abnormally high creep rates studied. Testing of the reliability of long-time creep tests deduced from short-time tests is described. Relaxation tests enabled a mathematical relation between relaxation time and stress to be derived. Investigations into the effects on the properties of the steel, of the presence of minor elements and the method of manufacture are described. (22 references).—P. M. C.

Gas Turbine Progress Report—Materials, Cooling, and Fuels. A. A. Hafer. (*Trans. Amer. Soc. Mech. Eng.*, 1953, **75**, Feb., 127–136). American alloys used in gas turbine engineering are listed with typical stress rupture properties. The use of ceramics and ' cermets ' is briefly mentioned. Various types of cooling technique are discussed and a review is given of the available fuels and methods used to prevent ash deposition and attack.—(97 references).—D. H.

The Rôle of Thermal Conductivity in Combustion Turbines and the Steels for Valves. R. de Fleury. (*Métaux–Corrosion–Indust.*, 1953, **28**, Mar., 133–134). The influence of the thermal conductivity of the parts used for the construction of gas turbines is briefly considered.—B. G. B.

Some Reflections on the Thermal Distortion of Turbine Casings. B. J. Terrell. (*Inst. Mech. Eng., Preprint, Conf. on Steam Turbine Research and Development*, 1953, Mar. 6, 37–46). An attempt is made to analyse ways in which the casings of steam and gas turbines distort under heating and cooling conditions. The derivation is included of a criterion for the susceptibility of materials to thermal distortion expressed as

$$\frac{1-\mu}{E\alpha}\left\{\frac{k}{hd}\right\}^{0\cdot57}$$

where μ = Poisson's ratio, E = Young's nodulus, α = coefficient of thermal expansion, k = thermal conductivity, h = surface heat-transfer coefficient, and d = the thickness of the wall (assuming a cylindrical casting). Values of α, E, k, the maximum permissible stress, and the distortion criterion are tabulated for a 0·25% carbon steel, (as forged, normalized, normalized and tempered, and annealed), a 0·28% carbon, 0·66% molybdenum steel, normalized ; a 12% Cr–Mo–V ferritic stainless steel, hardened and tempered ; and an 18/10 Cr–Ni niobium-bearing austenitic steel. The values are given for several temperatures up to 1000° F. The austenitic stainless steel is by far the worst, and the ferritic stainless is by far the best from the thermal distortion point of view. Finally, some practical cases of distortion are discussed.

Steels for High Steam Temperatures. C. Holzhauer. (*BWK*, 1953, **5**, July, 234–236). The development of steels for use at high temperatures, and of methods for determining their performance, is surveyed. It has become necessary to reject the demand for a safety factor, which would ensure indefinite operation of a steel at high temperature in favour of determining experimentally the expectation of life of steel parts under operating conditions, and then to replace them periodically.—P. F.

The Elastic Modulus of Materials at Elevated Temperatures, Particularly of Turbine Blade Steels. J. Vodsed'álek. (*Strojirenství*, 1953, **3**, 5, 370–377). [In Czech]. Principles and methods involved in determining Young's modulus of metals at high temperatures by static and dynamic methods are discussed. Young's moduli of a number of creep-resisting steels of Czechoslovak and foreign make were determined up to 900° C., and the results are given.—P. F.

Superheater Tubes: Effect of Phosphorus on the High Temperature Properties of a 0·5% Mo Steel. M. G. Gemmill and J. D. Murray. (*Iron Steel*, 1953, **26**, July, 347–350). High-temperature tests made on ten experimental and two commercial casts of low-carbon, 0·5%-Mo steel, with phosphorus ranging from 0·01% to 0·11%, show the beneficial effect of phosphorus, particularly up to 0·06%, on low deformation creep characteristics. Rupture strength increases regularly with increasing phosphorus, but ductility decreases. The experimental data are considered in relation to more recent theories of plastic deformation.—G. F.

Doing More With Less Nickel. E. A. Schoefer. (*Steel*, 1953, **133**, Aug. 3, 134–135). The results of the work of the U.S. Alloy Casting Institute on developing low-nickel alloys is reviewed. Particular attention is paid to resistance to hot gas corrosion and high temperature mechanical properties.

Properties and Manufacture of Valve Steels for the Automotive Industry. J. Cameron. (*Metal Treatment and Drop Forg.*, 1953, **20**, Apr., 149–154 ; May, 213–218). The properties required in a steel suitable for valve manufacture are enumerated, and the factors governing the selection of steel composition are discussed. The compositions, manufacture, and properties of the following typical valve steels are described, En 24, 51, 52, 59; Silchrome X. Cr.; and DTD.49.B. Heat-treatment of valve steels is discussed, and detailed results are given to illustrate the effect of quenching and tempering on the hardness and impact strength of En 52, En 59, and Silchrome X. Cr.—P. M. C.

Which Metal Form for Jet Engine Blades? J. L. Everhart. (*Mat. Methods*, 1953, **37**, Feb., 92–96). The effect of production method on the quality and service performance of jet engine blades, vanes, and buckets is discussed. The characteristics of such components as produced by forging, casting, machining and grinding, and by powder metallurgy methods are described.—P. M. C.

High Temperature Alloys for Gas Turbines. H. V. Kinsey. (*Canad. Metals*, 1952, **15**, Oct. 28–30 ; Dec., 20–24). This is a review of alloys used in gas turbines. A brief appraisal of the stresses and temperature distribution across the disc and blades is given, and then a broad classification is made by dividing the iron alloys into the ferritic-martensitic and the austenitic types. Examples are quoted in each class with the relevant mechanical properties, and a general summary on the advantages and disadvantages of the alloys for their particular applications. The development of new alloys is discussed.—J. C. B.

What the Ferrous Metallurgist Should Know About Titanium. R. I. Jaffee. (*Iron Age*, 1953, **171**, Apr. 2, 162–166). The heat-treatment of titanium alloys and how it differs from steel are explained. Normal steel treatment is not applicable, particularly for alloys of titanium with interstitial elements like carbon, because the crystal structures of the allotropes of titanium are reversed. The alloys with beta stabilizing elements offer quench hardening possibilities, but these are poor because retention of beta phase does not permit full hardening and causes trouble during tempering. Age hardening is also difficult. Alpha–beta-type titanium alloys should be used in the fully stabilized condition.—A. M. F.

The Amsler Apparatus for Study of High Temperature Fatigue Using High-Frequency Electromagnetic Vibrators. A. Tenot. (*Metaux–Corrosion–Indust.*, 1953, **28**, Mar., 135–140). A machine is described for the study of the fatigue of high temperature alloys at temperatures up to 800° C. Full details of the operation of the machine and of the auxiliary equipment are given.—B. G. B.

The Influence of Nickel on Oxygen Solubility in Molten Iron-Chromium-Nickel Alloys. B. V. Linchevskii and A. M. Samarin. (*Doklady Akademii Nauk S.S.S.R.*, 1953, **89**, 5, 867–868). [In Russian]. The influence of nickel on the oxygen solubility in Fe–Cr–Ni alloys was determined at 1625° C. The chromium content was varied from 4 to 20% and the nickel content from 3 to 22%. It is shown that nickel increased the solubility of oxygen in the molten alloy.

The Effect of Grain Size on the Hydrogen Permeability of Iron. H. Schumann. (*Met. u. Giesserei Techn.*, 1953, **3**, Apr., 123–126). An examination of the literature shows that some investigators postulate intercrystalline, others intracrystalline migration. Experiments have failed to confirm either view. The author considers hydrogen diffusion as a quality influenced

by structure. Contradictions can then be reconciled as it appears that the effect of grain size is masked by contamination.—L. J. L.

Elimination of Nitrogen Dissolved in Iron by Addition of Aluminium. T. Saitô and K. Maruya. (*Sci. Rep. Res. Inst. Tôhuku Univ.*, 1952, **A4,** Dec., 622–632). [In English]. Nitrogen can exist as AlN or as an interstitial solution in Fe–Al alloys : the amount of the latter bears a relationship to aluminium content explainable in terms of thermodynamics and lattice properties. At 1 atm. pressure, nitrogen reacts with pure molten aluminium to form AlN only.—K. E. J.

Nitrogen as Alloying Element in Steels. II.—On the Effect of Nitrogen on Blue Brittleness in Steels. Y. Imai and T. Ishizaki. (*Sci. Rep. Res. Inst. Tôhuku Univ.*, 1952, **A4,** Dec., 553–574). [In English]. The effect of nitrogen on blue brittleness in carbon steels was investigated by tensile tests up to 300° C. Nitrogen was the principal cause, although carbon produced brittleness at high temperature in steels of low nitrogen content. Blue-brittlneess was reduced by manganese. Titanium and aluminium were effective agents for denitriding by fixation.—K. E. J.

The Influence of Hydrogen Diffusion on the Critical Deformation of Unalloyed Mild Steel. F. Erdmann-Jesnitzer and H. Schumann. (*Arch. Eisenhüttenwesen*, 1953, **24,** May–June, 211–213). The grain growth of mild steel when annealed in hydrogen has been attributed to the effect of the diffused gas in increasing the amount of deformation to above the critical value. Experiments have been conducted on specimens deformed to just below the critical value, charged in various ways with atomic hydrogen and then annealed. No grain growth was found, except superficially, and this was due to decarburization.—J. P.

Some Small Electric Resistance Furnaces for Use at High Temperatures (Up to 1350° C.) E. P. Jung. (*Métaux-Corrosion-Indust.*, 1953, **28,** Mar., 127–132). The construction, operation, and control of small electric furnaces for laboratory use are discussed. Nickel–chromium alloy elements are suitable for use up to 1100° C. Iron–chromium–aluminium elements are suitable up to 1350° C. but must not be allowed to come into contact with siliceous materials due to breakdown of the refractory alumina coating which forms on the surface.

Influence of Small Amounts of Nickel on the Quality of Chromium–Molybdenum and Chromium–Molybdenum–Vanadium Steels. J. Klärding. (*Draht*, 1953, **4,** Mar., 88–94). The results of an investigation into the effect of small amounts of nickel on the mechanical properties, hardenability and temper-brittleness of the above steels are reported. In general, the small amounts of nickel present make little difference to these properties.—J. G. W.

Cr–W–V Steels for Steam Turbines. Z. Eminger, Pokorny, and J. Slajs. (*Strojírenství*, 1953, **3,** 6, 444–452). [In Czech]. Tensile, impact, and creep results obtained in long and short-time tests on several types of Cr–W–V steels, containing from 0·05 to 0·25% Mo as impurity, are given. With the exception of a somewhat lower notch impact strength, these steels were found to be practically equivalent to Cr–W–Mo steels conventionally employed for steam turbines.—P. F.

The Metallurgical Basis of ' Rollodur ' Tool Steel. (*Österr. Masch. Elektrowirtschaft*, 1952, **7,** Aug., 321–328). The metallurgical work on chromium steels, leading to the development in Switzerland of ' Rollodur ' tool steel for making cast milling cutters, is described. This material, which contains at least 8% Cr, at least 4% W, and suitable amounts of molybdenum, cobalt, and vanadium, is sufficiently stable and tough to allow large feeds to be used in milling. Its composition, heat-treatment, and casting are discussed.—H. R. M.

Russians Show Progress on Stainless and Heat-Resisting Steels. C. A. Zapffe. (*Iron Age*, 1953, **171,** Mar. 19, 138–142). A close comparison is made between similar American and Russian alloys using published Russian information. The general impression is that Russian technology of austenitic stainless steel is not up to date. One stainless alloy employs nitrogen as a substitute for nickel but there is a lack of free machining, work hardening and precipitation alloys. Amongst the heat-resisting steels, tungsten is the principal addition for hot strength, and silicon is widely used for scaling resistance.—A. M. F.

Wear and Fatigue of Rails. M. Roš. (*Rev. Mét.*, 1953, **50,** June, 389–409). Rails made from a single steel, heat-treated, and compound rails have been exhaustively examined in regard to their static and dynamic mechanical properties and wear after long service on the Gothard line. Properties of greatest importance are a high resistance to wear, a very high fatigue limit, and adequate bending capacity. Details of five suitable types of steel are given.—A. G.

Use Right Draw Speeds for Better Electrical Properties. S. Storchheim. (*Iron Age*, 1953, **171,** Apr. 9, 135–138). Stainless steel wire of types 302 and 304 has been drawn at speeds between 45 and 3900 ft./min. to determine the effect on remanence, coercive force, specific resistance, and tensile strength. In general, coercive force increases and the other three factors decrease. This is attributed to less martensite formation due to rise in temperature of the wire, maximum transformation from austenite takes place at about room temperature.—A. M. F.

Structural Applications of Stainless Steel. A. G. Dean. (*Engineer*, 1953, **195,** June 19, 853–855 ; June 26, 882–884). The author reviews 20 years of operating experience in the uses of stainless steel as a structural material. Special reference is made to the design of railway coach structures.

Types of Steels for Use in Welded Metallic Structures. H. Herbiet. (*Rev. Univ. Min.*, 1953, 9th series **9,** May, 368–374). The author examines the factors influencing the hardening and brittleness of different steels, particular attention being paid to the performance of some standard Belgian steels. Research in Belgium on this subject is outlined.—B. G. B.

Centrifugally Cast Steel Tubing. T. E. Rybka. (*Mat. Methods*, 1953, **37,** Feb., 104–107). The excellent characteristics of centrifugally cast tubing are discussed, emphasis being placed on its non-directional properties, freedom from segregation, and close tolerances. Sizes range from about 2 to 50 in. outside dia., wall thicknesses range from $\frac{1}{4}$ to 4 in. and lengths up to 16 ft. Many examples of typical applications are given, and the mechanical properties of tubes made from various grades of steel are tabulated.—P. M. C.

Effect of Various Elements on Hot-Working Characteristics and Physical Properties of Fe-C Alloys. C. T. Anderson, R. W. Kimball, and F. R. Cattoir. (*Trans. Amer. Inst. Min. Met. Eng.*, 1953, **197:** *J. Met.*, 1953, **5,** Apr., 525–529). This paper (the first of a series) outlines the results of a study of the effect of sulphur on the hot-forgeability and physical properties of iron-carbon alloys containing less than 0·004% Mn with low silicon and phosphorus. With more than 0·017% S the alloys could not be hot-forged, this property improving as the sulphur was decreased. The carbon content appeared to exert the principal influence on the physical properties.—G. F.

Role of Boron Steels in Alloy Conservation in the U.S.A. : A Study of Their Uses and Limitations. J. F. Sewell. (*Iron Coal Trades Rev.*, 1953, **166,** Apr. 17, 871–881, 884). The author discusses progress made in the United States in the use of boron steels, and assembles data on physical properties which are of interest to British metallurgists. The factors considered are hardenability, mass effect, heat-treatment, tensile properties, torsion tests, impact resistance, and fatigue. The applications and limitations of boron steels are discussed.

Replacement of Alloying Elements by Boron in Steels for Cementation and Thermal Treatment. R. Scherer and K. Bungardt. (*Rev. Mét.*, 1953, **50,** Feb., 73–94). The influence of small boron additions ($< 0{\cdot}005\%$) on the hardenability and mechanical properties of steel has been studied. In cementation steels boron augments hardenability and is equivalent to a content of 0·7% Mn + Ni + Cr. In heat-treatable steels boron replaces 0·5% Cr or Mn, or 0·15% Mo. Boron cannot replace vanadium or molybdenum where these elements have been added to improve high temperature strength or resistance to temper brittleness.—A. G.

Some Metallurgical Characteristics of Medium-Carbon Boron-Treated Steels. R. N. Imhoff and J. W. Poynter. (*Metal Progress*, 1953, **63,** Mar., 97–104). The physical properties of three American steels containing 0·3 to 0·43% carbon and some boron are compared with those of standard steels which they can replace. The properties investigated are those of primary interest to the aircraft industry and include hardenability, notch tensile strength, notch impact strength, temper brittleness, and rotating-beam fatigue strength.—B. G. B.

Selection of Materials for Use in Chemical Engineering. J. P. Baxter. (1952 Welding Engineering Convention : *Australasian Eng.*, 1952, Dec. 8, 62–65). The development of the chemical industry has depended to a large extent on

the development of new materials and welding techniques. Available materials, both ferrous and non-ferrous, are briefly enumerated, and their uses and limitations discussed.—P. M. C.

Stainless Steel—Properties of Material. H. R. Dalziel. (1952 Welding Eng. Convention : *Australasian Eng.*, 1953, Jan. 7, 53–58). Six typical stainless steel compositions, four austenitic, one martensitic, and one ferritic, are listed and their general characteristics outlined. Their mechanical, physical, and corrosion resisting properties are discussed and tabulated, and data concerning their resistance to organic acids are given.—P. M. C.

The Use of Stainless Steel in the Chemical Industry. W. B. Clarke. (1952 Welding Eng. Convention : *Australasian Eng.*, 1953, Jan. 7, 59–65). The paper is confined to a discussion of the 18/8 type austenitic stainless steels. Brief details of mechanical properties, heat-treatment, and code requirements are given. Methods of fabrication, welding, cutting, and flanging are discussed.—P. M. C.

Some Physical Properties of Investment Cast Alloys. K. J. Yonker. (*Precision Met. Mold.*, 1953, **11,** Feb., 42–43). The mechanical properties of a number of investment cast alloys as determined by the Howard Foundry Co. over a period of years are given in tabular form. Details are given of Cr–Ni–Mo steels with 0·20%, 0·30%, and 0·40% of carbon, and of a number of Cr–Ni stainless steels.—D. H.

What Steel for Enamelers ? M. B. Gibbs and F. R. Porter. (*Steel*, 1953, **132,** June 1, 108–109, 131–135). The authors compare the working and enamelling properties of various types of sheet, with a view to assisting in the choice of the most economical materials available. Some substitutes for enamelling iron hold considerable promise.—D. L. C. P.

Specifications and Their Application to Thick Plates. J. Bernard. (*Rev. Mét.*, 1953, **50,** May, 352–356). The growing demand for heavier steels together with the difficulties inherent in their manufacture necessitate a modification of existing out of date specifications. Possible amendments are considered.—A. G.

Manufacture and Uses of Killed, Semi-Killed and Unkilled Steels. F. Franz. (*Met. u. Giesserei Techn.*, 1952, **2,** Nov., 393–398). The differences between the above three types of steel with regard to the formation, intentional and otherwise, of blowholes and pipe, and to their mechanical properties are described. A comparison is made of impact values obtained from specimens of metal plates 10–15 mm. thick of killed and unkilled steel.—L. J. L.

Some Recent Alloy Steels and Their Heat-Treatment. W. C. Mearns. (*Metal Treating*, 1953, **4,** Mar.–Apr., 2–4, 10). The author discusses the compositions, properties, and heat-treatment of two types of alloy steel which have found application in specific fields. These are the age-hardening steels containing up to 5% Ni and 2% Al, and the extra high strength steels such as the 0·5% Cr, 2·50% Ni, 0·5% Mo, and 0·2% V. After quenching and reheating in the 1200–1275° F. range, the age hardening type has a Rockwell hardness of about C30, and can be finish machined. Subsequent ageing at 950°–1050° F. develops a hardness of C40–C46 without further deformation. The extra high strength steels, which can be heat-treated to tensile strengths in the range of 200,000–300,000 lb./sq. in., have higher strength/weight factors than aluminium alloys.—P. M. C.

Physical Properties of Steel as Functions of the Tempering Temperature. A. A. Peebles. (*Engineering*, 1953, **175,** May 15, 613–615). The author shows from experimental work that, when an annealed steel is hardened and subsequently tempered, the principal physical properties may be expressed as mathematical functions of the tempering temperature. By correlating the equations obtained, the major physical properties can be deduced from any one of such properties which has been experimentally determined.—J. McK.

Influence of Tempering on the Properties of Steel Wire. W. Püngel and R. Hünlich. (Mitteilungen Kohle- u. Eisenforschung : *Wire Prod.*, 1952, **2,** Dec., 4–5, 7). Results of an investigation are summarized, in which the effect of 20 sec. tempering at 350, 450 and 550° C. on the properties of hard drawn rope wires was studied. The treatment markedly increased the 0·01% proof stress and had less influence on the tensile strength, reduction in area, and elongation.

Fatigue Strength and Resistance to Wear of a Case-Hardening Alloy Steel after Normal and Isothermal Hardening. H. Tauscher. (*Met. u. Giesserei Techn.*, 1953, **3,** Feb., 54–58). Experiments were carried out with a case-hardening alloy steel (Mn 1·17%, Cr 1·55%) to investigate the effect of normal and isothermal hardening, respectively, on resistance to wear, bending fatigue strength, and notch toughness.—L. J. L.

The Problem of the Standardization of High-Speed Steels. R. Mitsche. (*Berg- hüttenmänn. Monatsh.*, 1952, **97,** Dec., 225–227). The author discusses problems of standardization of alloy tool steels, with special reference to German, Swedish, and American standard high-speed steels of the Cr–Mo–V–W–Co type.—P. F.

Application of Isothermal Heat-Treatment to Mn-Si Spring Steels. P. G. Boting. (*Metalen*, 1953, **8,** Jan. 31, 21–25). [In Dutch]. Isothermal quenching tests on silico-manganese spring steels showed that the ductility can be increased.—R. S.

Experiments on the Development of a Wear-Resistant Medium Hard Roll Using Nodular Graphite. H. Goebel. (*Giesserei Technisch-Wissenschaftliche Beihefte*, 1952, Mar., 463–475). The advantages of a spherolitic cast texture for wear-resistant properties are considered theoretically. The stresses in a medium hard rolling-mill roll are then considered from the mechanical and thermal view point. Experiments are described in detail, using different types of cast iron with various carbon, manganese and phosphorus contents and with additions of magnesium. The wear-resisting and other mechanical properties were investigated and were correlated with the texture, especially the graphite formation.—R. J. W.

Nodular Iron, Its Properties, and Recent Progress. G. Mohr. (*Mét. Constr. Mécan.*, 1953, **85,** May, 375–377). The physical properties of a number of nodular cast irons are given in tabular form and are compared with those of ordinary cast irons and steels. Examples of the applications of nodular iron are given.—B. G. B.

What is Meehanite? E. Piwowarsky. (*Giesserei*, 1953, **40,** July 9, 354–359). The historical development of the Meehanite Metal Corp. (U.S.A.) is followed, the material Meehanite is described and the working methods of the Meehanite control system discussed. The different types of Meehanite are classified and their physical properties tabulated. They fall into four main categories : (*a*) For general use ; (*b*) heat resistance ; (*c*) wear resistance ; and (*d*) corrosion resistance. These grades are compared with grey cast iron with regard to different properties.—R. J. W.

Specification for Ductile Iron. G. Sorkin. (*Steel*, 1953, **132,** June 22, 86–87). The specification for 'Castings of Nodular Iron Type', issued by the U.S. Bureau of Ships is described. Low phosphorus raw materials, and a careful ferritizing anneal are implied. Already authorized for uses such as compressors, electrical equipment, and cylinder blocks, applications of the material are expected to grow.

Wear Properties of Ductile Cast Iron. (*Product Eng.*, 1953, **24,** Feb., 125–127). This article presents wear test data and cites case histories to show that the wear resistance of ductile iron is substantially the same as that of grey cast iron. In the application of ductile cast iron to gears, examples have shown considerably better wear resistance than grey iron. Further comparative examples of piston rings and cylinders, bearings, and dies are given.—A. M. F.

The Density of Molten Iron. V. H. Stott and J. H. Rendall. (*J. Iron Steel Inst.*, 1953, **175,** Dec., 374–378). [This issue].

A Malleable Cast Ferrous Alloy with Good Hardening and Welding Properties. (*Machinery*, 1953, **82,** June 12, 1106–1108). Overum steel has been developed by A. B. Overums Bruk, Overum, Sweden. It has a tensile strength range from 25 to 89 tons/sq. in., and elongation from 16 to 1·5%, depending on the hardness which may vary between 180 and 400 Brinell. It can be forged at a temperature of 1724° F. and welded by electric arc. Twice the wear resistance of carbon steel is claimed for this new alloy. Detailed results of tests are given.—E. C. S.

Malleable Iron Castings. H. R. Clauser. (*Mat. Methods*, 1953, **37,** Mar., 109–124). Malleable iron castings are useful engineering materials, which in the author's opinion, have not in the past received the attention they deserve. Their unusual combination of properties including excellent toughness, corrosion resistance, machinability, and castability, suit them for a wide range of uses. This article is to familiarize engineers and designers with the properties, characteristics, and uses of the various types of malleable castings. The information presented includes : Types of malleable irons ; engineering properties ; design adaptability ; processing characteristics; and applications.—P. M. C.

Vacuum Metallurgy Grows: Can You Use It? A. G. Gray. (*Steel*, 1953, **132**, June 29, 88–91). High vacuum metallurgical furnaces now offer a practical method for producing metals and alloys having properties not obtainable by conventional processing. Results achieved, types of furnace and equipment used are described, with examples. Tests on vacuum-cast steels show improved fatigue and stress properties. Wire can often be drawn to a finer size. Alloying elements are effective in smaller quantities. Ball-bearings of exceptional durability are produced from vacuum-melted steels. Surface characteristics of sheet are noticeably improved. Success of processing in vacuum depends on complete elimination of gases from melt before pouring. These steels are commercially available in America.—D. L. C. P.

Vacuum Melting Lengthens Fatigue Life, Improves Impact Properties. J. H. Moore. (*Iron Age*, 1953, **171**, Apr. 2, 154–156). Marked differences in fatigue life of vacuum melted and commercial type medium-chromium steels have been found after tests in a rotating beam machine. In terms of stress this means an increase of about 40% for the same life. A small but definite increase in impact properties was also found. It is suggested that extra metal cleanliness is an important factor in improving the properties.—A. M. F.

New Laboratories of the Guest, Keen and Nettlefolds Group. (*Iron Coal Trades Rev.*, 1953, **166**, May 29, 1239–1240; *Engineering*, 1953, **175**, June 5, 715–716; *Metallurgia*, 1953, **47**, June, 283–286; *Brit. Steelmaker*, 1953, **19**, June, 384–386; *Metal Ind.*, 1953, **82**, June 5, 459–460, 462). A brief description is given of the newly established headquarters and laboratories of the G.K.N. central research organization at Wolverhampton. The total floor area is 40,000 sq. ft., and the staff at present comprises 115 people, of whom some 40 are graduates in various branches of science and technology. The laboratory has three main functions: (1) To carry out research and development work of direct and immediate interest to Group firms, on processes, materials, and testing methods; (2) to carry out long term fundamental research; and (3) to provide a general laboratory service for those units of the Group too small to maintain their own laboratory.

Scientific Research of Philips' Industries from 1891 to 1951. W. de Groot. (*Philips Tech. Rev.*, 1951, **13**, July–Aug., 3–47). A review is presented of the history and development of the activities of the Physical Research Laboratory of Philips' Industries, founded in 1914. The greater part of the review deals with the work of the new laboratory, built in 1923.—P. M. C.

Vacuum Techniques in Metallurgy. W. J. Kroll. (*Times Review of Industry*, 1953, **7**, Aug., 26–31). The use of vacuum techniques in the extraction and purification of metals is discussed and descriptions are given of apparatus for melting titanium and zirconium.—R. A. R.

A High-Temperature High-Vacuum Furnace for Experimental Work. H. D. Blakelock and C. F. Machin. (*Engineer*, 1953, **196**, July 17, 83–84). The heating element in the furnace described is a slotted cylinder of graphite suitable for a three-phase supply. For a working temperature of 2000° C. the furnace loading is less than 6 kW. (12 references).

METALLOGRAPHY

A New Incident Light Phase-Contrast Microscope. F. Gabler. (*Radex Rundschau*, 1952, No. 5, Oct. 210–215). The principles of transmitted light phase-contrast microscopy are explained and the adaptation of the method for incident light work is discussed. A suitable microscope attachment made by C. Reichert, Vienna, is described, comprising interchangeable phase-contrast plates and an ocular system as well as an auxiliary focusing microscope.—E. C.

Applications of Phase-Contrast Microscopy in Mining and Metallurgy. R. Mitsche. (*Radex Rundschau*, 1952, No. 5, Oct., 216–221). Incident light phase-contrast microscopy is introduced in brief and examples are shown of its application in the study of polished surfaces of metals, ores, and refractories.—E. C.

Modern Methods for the Microscopical Examination of Metal Surfaces. F. Gabler. (*Metall*, 1953, **7**, June, 401–405). The following methods employing Reichert equipment are explained and discussed: Light and dark field illumination, oblique illumination, phase contrast, light slit, and interference examination of surface finish. (12 references).

The Ultraviolet Microscope. E. W. Taylor. (*J. Opt. Soc., Amer.*, 1953, **43**, Apr., 299–305). A form of ultraviolet microscope of the refracting type is described in which the source of radiation is a spark gap between fixed or rotating electrodes and the objectives are normally monochromats. The microscope is horizontal, thus avoiding the use of a mirror, and the fine motion mechanism responds to movements of 0·10 micron. Phase contrast may be used for visual scanning of the object and also for photography in the ultraviolet. Some examples of microphotographs are given.

An Improved Scanning Electron Microscope for Opaque Specimens. D. McMullan. (*Proc. Inst. Elect., Eng.*, 1953, **100**, June, 245–259). An outline is given of previous developments in scanning electron microscopes, and methods of examining opaque specimens. A new electrostatically focussed instrument for opaque specimens is then described. (40 references).—L. D. H.

New Method of Preparing Replicas for the Electron Microscope Examination of the Surface Structure of Metals. I. Sugár. (*Acta Technica*, (Budapest), 1952, **5**, (1), 57–68). [In Russian]. Polystyrene-silica replicas were not satisfactory for replicas for the study of graphite in cast iron. Bimetallic films, which could be produced as thin as 40–50Å, showed many advantages, especially with regard to resistance to mechanical treatment and electron bombardment. A detailed description of the preparation of gold–aluminium replicas is given; these gave extremely good image contrast and better resolution.—R. A. R.

A Highly Stable Automatic X-Ray Diffraction Apparatus with Only One Moving Part. C. K. Jones. (*Rev. Sci. Instruments*, 1953, **24**, May, 380–387). Modifications are described to an existing apparatus taking diffraction patterns with the aid of Geiger-Müller counters. These modifications, which consist of an ionization gauge which keeps constant the intensity of the irradiating incident beam, and the use of a 'square-wave' method of counting, give diffraction records which are reproducible within limits set by statistical fluctuations.

A Symposium of 40 years of X-Ray Analysis. (*Chem. Week.*, 1952, **49**, Feb. 7, 81–104). [In Dutch]. This Symposium was held at Utrecht on June 13, 1952, under the sponsorship of the Nederlandsche Chemische Vereeniging, Physical and Colloid Chemistry Section, to review the progress of X-ray analysis since Laue presented in 1912 his memorable paper on the Interference Phenomena of X-Rays before the Bavarian Academy of Sciences. The following papers were presented:

40 Years of X-Ray Diffraction by J. M. Bivoet. (81–85).

X-Ray Analysis Procedures by C. H. MacGillavry and E. H. Wiebenga. (85–95).

Development of Diffraction Apparatus by G. D. Rieck. (95–99).

Technical Aids in X-Ray Analytical Calculations by J. C. Schoone. (99–104).

Electropolishing—In a Scientific Light. (*Dansk. Tekn. Tidsskr.*, 1953, **77**, Feb., 29–30). [In Danish]. Tedious polishing of ground specimens is obviated by two Danish devices. The Micropol, originally developed for testing a new Belgian electrolyte, is portable and permits examination of tool cutting edges without undue damage, the polished area being only 1 mm. in dia. Polishing is completed within 3–5 sec. after a preliminary ½–1 min. grinding. A larger model, the Disa Electropol, will polish in 10–30 sec.—G. G. K.

Electrolytic Polishing of Mild Steel Specimens—Study of the Roughness. G. Van Dijck. (*Soc. Roy. Belge. Ing. Bull.*, 1952, Oct., 225–230). The electrolytic polishing of mild steel specimens was carried out using an electrolyte consisting of alcohol and perchloric acid with a high current density of 200 amp./sq. dm. Under these conditions polishing was very rapid and times between 1 and 60 sec. were usual. The roughness of the specimens was measured by the movement of a sensitive stylus. The results of experiments carried out on a number of specimens of different initial roughness and polished for various times are given. Long polishing times were not required; the maximum amount of polishing occurs very rapidly at the commencement of the treatment. The rougher the specimen the greater the removal of material. Some curvature of the surface of the specimens was found due to irregularities in the current density across the specimen.

Alpha- and Epsilon-Phase Formation in Rapidly Cooled Fe-Mn Alloys. J. G. Parr. (*Metal Treatment and Drop Forg.*, 1953, **20,** Mar., 139–140). A qualitative theory is briefly outlined which explains the formation of α and ε phases in quenched Fe–Mn alloys in terms of their athermal nucleation from strain embryos. (15 references).—P. M. C.

Mechanism of Metal Deformation. (*Tekn. Tidskr.*, 1953, **83,** June 2, 475–476). [In Swedish]. The mechanism of crystal slip and the formation of slip bands are outlined. Details are given of deformation due to phase transformation and of the difficulty of distinguishing between it and slip.—G. G. K.

Deformation of Ferrite Single Crystals. F. L. Vogel, jun. and R. M. Brick. (*Trans. Amer. Inst. Min. Met. Eng.*, 1953, **197**: *J.Met.*, 1953, **5,** May, Section 2, 700–706). Results of experiments on the deformation of single crystals of ingot iron are given. Plastic deformation occurs by apparent glide in the <111> direction on a plane determined by the orientation of the crystal with respect to the stress axis, and by the variation of resistance to shear of the planes containing this direction. The work of other investigations is summarized.

Notes on the Plastic Critical Temperature in Strain-Induced Martensite Reactions. D. C. Starr. (*Trans. Amer. Inst. Min. Met. Eng.*, 1953, **197** ; *J. Met.*, 1953, **5,** May, 654). In studies of the martensite reaction, the author shows that the observation of a so-called plastic critical temperature, above which martensite cannot be formed isothermally by plastic deformation, is dependent on the mode of deformation and has no theoretical significance.—G. F.

X-Ray Studies of Polycrystalline Metals Deformed by Rolling. I—The Examination of the Harder Metals, Copper, Nickel and Iron. P. Gay and A. Kelly. (*Acta Crystallographica*, 1953, **6,** 2, 165–172). [In English]. The X-ray microbeam technique developed by Hirsch and co-workers has been used to determine the mode of deformation and the structure of the cold-rolled metals. From the microbeam photographs both the grain size and the angular misorientations may be determined, and a theoretical proof is given to show how an upper limit may be set to the particle size by measurement of the angular extent of the arcs in the Debye- Scherrer rings. In all three metals, with increasing deformation, the particle size decreased and the total angular misorientations within one original grain increased. In some specimens it was possible to show that both the particle size and particle distortion were contributing to line-broadening. It is concluded that the cold-rolling produces particles of size $>10^{-5}$ cm. and that these regions of relatively low distortion are separated by regions of greater distortion. There was no evidence in any specimen for spontaneous recrystallization after rolling, nor of self-recovery in the copper specimens.—B. C. W.

Secondary Recrystallization Textures and their Origin in Cold-Rolled Single Crystals of Silicon-Iron. O. G. Dunn. (*Acta Metallurgica*, 1953, **1,** Mar., 163–175). Single crystals of commercial 3½% iron-silicon alloy have been cold rolled and annealed to obtain different stages of primary and secondary recrystallization. Grain size and orientation studies were made using X-ray, metallographic and torque magnetometer measurements. The results show that secondary grains having specific preferred orientations grow from large primary grains whose orientation deviates markedly from the primary recrystallization texture. The driving force for secondary recrystallization comes from grain-boundary energy.—A. D. H.

Experimental Study of the Work-Hardening of Metals by Diffraction of a Fine X-Ray Beam. P. B. Hirsch. (*Rev. Mét.*, 1953, **50,** May, 333–340). The technique using an X-ray beam only a few microns in diameter is described. Results are given for various metals including iron rolled with 60% reduction. It is found that crystalline block size diminishes with progressive hardening to a minimum (1μ for iron) in disagreement with values calculated from the spread of the Debye-Scherrer pattern. Curves of block size, distortion, and disorientation as a function of deformation are given, and the results are discussed in the light of the dislocation theory.—A. G.

Inter-Crystalline Fracture and Twinning of Iron at Low Temperatures. J. R. Low, jun., and R. G. Feustel. (*Acta Metallurgica*, 1953, **1,** Mar., 185–192). The relationship between carbon content and the mechanism of fracture in tension of iron at −195° C. has been investigated. Decarburization by moist hydrogen yields a brittle material with intercrystalline fracture, whereas re-carburization restores ductility and leads to transcrystalline fracture. It is suggested that grain boundaries in pure iron are surfaces of low cleavage strength and that small amounts of carbon greatly increase this property. Twinning is not believed to be a cause of the brittleness.—A. D. H.

Further Notes on the Shape of Metal Grains: Space-Filling Polyhedra with Unlimited Sharing of Corners and Faces. C. S. Smith. (*Acta Metallurgica*, 1953, **1,** May, 295–300). A correction is made to a statement in an earlier paper that there is a limit to the sharing of corners in a network of cells analagous to metal grains. New space-filling irregular polyhedra sharing faces with up to 20 neighbours are sketched.

Anisotropic Elasticity with Applications to Dislocation Theory. J. D. Eshelby, S. T. Read, and W. Shockley. (*Acta Metallurgica*, 1953, **1,** May, 251–259). A general theory of anisotropic elasticity for a three-dimensional state of stress is developed and applied to the dislocation theory.

Experimental Verification of the Twin System in Alpha-Iron. H. W. Paxton. (*Acta Metallurgica*, 1953, **1,** Mar., 141–143). It is confirmed by optical goniometry, using a polished single crystal fractured at − 185° C., that the twinning plane is {112}, the twinning direction <111>, and the angle of shear is 38° 56′.—A. D. H.

The Estimation of Dislocation Densities in Metals from X-Ray Data. P. Gay, P. B. Hirsch, and A. Kelly. (*Acta Metallurgica*, 1953, **1,** May, 315–319). X-ray methods are described for estimating the density of dislocations in cold-worked metals. Results are presented for iron and seven other metals.—A. D. H.

The Hardening of Metal Crystals by Precipitate Particles. J. C. Fisher, E. W. Hart, and R. H. Pry. (*Acta Metallurgica*, 1953, **1,** May, 336–339). The hardening effect of precipitate particles is calculated in terms of a model in which the interaction of the dislocations and the particles causes an increase in the critical stress. Agreement with experimental data is fair.

Research on the Existence of Carbide Precipitates During the Ageing of Iron–Carbon Alloys by Means of Optical and Electronic Micrography. H.-J. Seeman, D. Hartnagel, and U. Hintzpeter. (*Rev. Mét.*, 1953, **50,** Feb. 95–104). The phenomenon of ageing has been studied in steels of varying purity and carbon content. The transformations observed have been related to the kinetics of carbide precipitation and results indicate that nitrogen does not influence the mechanism.

Influence of Stress on Martensite Nucleation. J. C. Fisher and D. Turnbull. (*Acta Metallurgica*, 1953, **1,** May, 310–314). Using nucleation theory, expressions are derived from the energy of formation and the volume of a critical size nucleus of martensite. The variation of M_s with stress is calculated and the agreement with experiment is good. The importance of stresses resulting from plastic deformation and previous transformation, and the rôle of dislocations are considered.

Crystallography of Phase Transformations. A. H. Geisler. (*Acta Metallurgica*, 1953, **1,** May, 260–281). A general classification of the structural aspects of diffusionless and diffusion-controlled transformations based on interfacial surface energy, strain energy and diffusion is proposed. For diffusion-controlled Widmanstätten structures, crystallographic relationships are dominant, whereas for diffusionless martensitic structures, strain energy factors modify those established by internal surface energy requirements. The consequence of spontaneous deformation by slip is illustrated for martensitic transformations in iron alloys. It is considered that the (111)A habit and the Kurdjumow-Sachs relationship are primitive characteristics of the γ→α transformation.—A. D. H.

Some Applications of the Thermodynamic Theory of Irreversible Processes to Physical Metallurgy. E. S. Machlin. (*Trans. Amer. Inst. Min. Met. Eng.*, 1953, **197** : *J. Met.*, 1953, **5,** Mar., 437–445). The author outlines the thermodynamic theory of irreversible processes and extends the theory to irreversible growth processes occurring by the motion of an interface. Theory is then applied to grain boundary migration, rate of growth of a stable phase, growth of a stable phase in a supersaturated matrix, and plastic deformation.

Temperature Dependence of Mechanical Properties of Metals in Relation to Their Crystal Structure. E. M. Savitskii. (*Doklady Akademii Nauk S.S.S.R.*, 1953, **89,** 1, 85–88). [In Russian]. The relation between the crystal structure of

metals and changes in their mechanical properties with temperature is experimentally demonstrated. The correlation established between mechanical properties and changes of crystal structure permits a qualitative prediction of the effect of temperature on mechanical properties of mono- and polymorphic metals, and solid solutions of these metals, provided that their crystal structure is known.—V. G.

A Conference on the Applications of X-Ray Spectroscopy to Solid State Problems. (*University of Wisconsin*, Oct. 23–25, 1950). This conference was held under the joint sponsorship of the Wisconsin Alumni Research Foundation and the Department of the Navy Office of Naval Research. Abstracts of the papers of interest follow :

Notes on X-Ray Spectra and the Theory of Solids. N. F. Mott. (pp. 1–7). Certain aspects of the electronic theory of solids, in which progress may be made through the study of X-ray absorption spectra, are discussed.

The X-Ray K Absorption Edges of Covalently Bonded Cr, Mn, Fe, and Ni. G. Mitchell and W. W. Beeman. (pp. 63–68). Low-energy absorption (generally resolved as a line) is observed in all complexes where an empty $4p$ orbital is expected from chemical or magnetic data. From the position of the line it is concluded that the metal ion is near neutral in the covalent complex. Where the $4p$ orbital is completely used in bonding, no low-energy absorption is observed. The method may be useful as an additional experimental check on the assignment of bonding orbitals.

A New Bent Crystal Spectrograph with High Resolving Power Designed for the Study of Absorption Spectra in the Solid State. A. E. Sandström. (p. 69). Brief particulars are given of a very large new spectrograph for crystal radii up to 2 m. at the University of Uppsala, Sweden. The instrument is enclosed in a very large vacuum tank (2·5 cu. m.). All movable parts can be manipulated from the outside. It has a linear dispersion which covers the angle range of 30° to 80°. A full description of the instrument is to be published shortly.

Metallographic Structure of Austenitic Alloys Especially Those of the 18/8 Type. II—Diffusion Reactions in Austenitic Structures with a Large Amount of Alloying Elements. P. Bastien and J. Dedieu. (*Métaux–Corrosion–Indust.*, 1953, **28,** Mar., 95–101). The effect of temperature, composition, and cold working on the rate of diffusion is first considered. The rates of diffusion of several elements in iron are compared. The influence of plastic deformation, a hard structure, and the bainite and troostite reactions on the rate of diffusion are discussed.—B. G. B.

Condition of Carbide Formed During Isothermal Decomposition of Austenite. E. G. Azintsev and E. G. Arbuzov. (*Zhurnal Tekhnicheskoi Fiziki*, 1950, **20,** 1, 32–37). An X-ray investigation of carbide powders isolated from samples of a plain carbon steel after isothermal decomposition of austenite at various temperatures is described. On the basis of experimental evidence it has been established that the carbide formed at various temperatures of isothermal decomposition has an orthorhombic lattice with constants similar to that of cementite. The widening and disappearance of some lines in the X-ray photographs observed at lower decomposition temperatures are explained by the plate-like shape and degree of dispersion of the precipitated carbide.

The Isothermal Transformation of Austenite in the Carburized Surface Layer of a Case-Hardening Alloy Steel, Particularly During the Intermediate Stage. H. Tauscher. (*Met. u. Giesserei Techn.*, 1953, **3,** Jan., 14–24). The author reports experiments with a case-hardening alloy steel 22MnCr6 containing 0·24% C, 0·23% Si, 1·17% Mn, 1·55% Cr, 0·053% P and 0·025% S, cooled to temperatures ranging from 220° to 560° C. Time–temperature–transformation curves are derived ; a mathematical evaluation of the tests is given ; the kinetics of transformation are examined ; and Vickers microhardness tests are evaluated.—L. J. L.

Electronic Origins of the Transformations and the Analogous Phenomena in Iron and the Nature of Its Spontaneous Magnetism. M. Satô. (*Sci. Rep. Res. Inst. Tôhuku Univ.*, 1952, **A4,** Dec., 597–605). [In English]. Structure levels of the valency electron in iron are deduced from reference to zinc and copper and temperature phenomena. The origins of transformations, such as A_3, A_4, melting points, and magnetic change at the Curie point, are explained in terms of electronic transitions between components of molecular multiples : spontaneous magnetism is due to the magnetic moment of the electron system. (15 references).—K. E. J.

Retained Austenite in Carburized Alloy Steels. W. J. Jabsen. (*Metal Progress*, 1952, **62,** Dec., 118, 120). Retention of austenite resulting from an incomplete transformation in the austenite–martensite reaction is usually associated with a too rapid quenching rate. The author gives examples where the reverse was found to be true.—B. G. B.

Effect of Shot Peening on the Transformation of Austenite. E. N. Bolkhovitinova. (*Vestnik Mashinestroeniya*, 1952, **32,** 5, 67–69). The influence of shot peening on the austenite transformation was investigated using a 0·18% carbon steel with additions of chromium, manganese, and titanium. Shot peening causes the austenite–martensite transformation to occur in the surface zone. The strain hardening effect, when using fine shot, penetrates to the depth of about 0·5 mm. The process is recommended for improving high-speed steel tools.—V. G.

The Phase Diagram Section A–BC (Ordered Compound). H. K. Hardy. (*Acta Metallurgica*, 1953, **1,** Mar., 210–217). Solutions between the A apex of the compositional triangle and BC, an ordered compound, in a ternary system are investigated by statistical mechanics. The theory is applied to the Fe–NiAl phase section and the agreement is satisfactory.

Rate of Formation of Isothermal Martensite in Fe–Ni–Mn Alloy. R. E. Cech and J. H. Hollomon. (*Trans. Amer. Inst. Min. Met. Eng.*, 1953, **197** ; *J.Met.*, 1953, **5,** May, Section 2, 685–689). The authors have investigated the austenite-martensite transformation characteristics of a 73%-Fe/23%-Ni/3·7%-Mn alloy. Isothermal transformation occurs in the range −79° to −196° C., the rate reaching a maximum at −128° C., and proceeds by delayed formation of martensite nuclei followed by rapid growth. Martensite formation can be suppressed completely by rapid quenching, and partial stabilization is achieved by ageing at room temperature.

Stabilization of the Austenite-Martensite Reaction in a High Chromium Steel. S. C. Das Gupta and B. S. Lement. (*Trans. Amer. Inst. Min. Met. Eng.*, 1953, **197** : *J. Met.*, 1953, **5,** Apr., 530–536). The authors have investigated the characteristics of the austenite-martensite reaction in 15%Cr, 0·7% C steel, primarily to study various aspects of stabilization. The effects of previous treatments on subsequent athermal and isothermal martensite formation at relatively low sub-zero temperatures are discussed in relation to the reaction-path theory.—G. F.

The Theory of the Growth of Pearlite. E. G. Eeles. (*J. B'ham. Met. Soc.*, 1953, **33,** Mar., 29–43). The modern theory of pearlite growth is discussed, with reference to both edge-wise growth and sideways nucleation and growth ; these involve the diffusion of carbon. (12 references).

Sub-Zero Treatment of Metals for Stabilization. R. S. Jamison. (*Metal Treating*, 1953, **4,** Jan.–Feb., 4, 5). The complete transformation of austenite to martensite in certain high-speed steels is not attained by quenching to normal temperatures. The advantages to be gained by cooling to −120° F. are discussed, with particular emphasis on increased hardness and dimensional stability. Sub-zero chilling units are commercially available in the U.S.A.—P. M. C.

CORROSION

Corrosion of Metals. P. T. Gilbert and H. S. Campbell. (*Reports on the Progress of Applied Chemistry*, 1952, **37,** 347–361). Recent advances in corrosion research and more important aspects of the corrosion problem as reported in the literature from January 1951 to September 1952 are reviewed. (194 references).—R. A. R.

In Corrosion Testing, Get the Facts. A. G. Gray. (*Steel*, 1953, **132,** June 15, 128–133). A conference on heat and corrosion resistant alloys is reported. It was sponsored by the International Nickel Co., and held at Wrightsville Beach on May 12–14, 1953. The International Nickel Co's. co-operative scheme for marine corrosion testing at Kure Beach is mentioned. Marine atmosphere and sea-water tests on the effect of additions to steels and irons, and the effect of surface condition, are described. Comparison is made between similar cast and wrought alloys with regard to corrosion. The addition of 1–2% Si is very effective in increasing the corrosion resistance of Ni–Cr alloys in flue gases containing sulphur.—D. L. C. P.

Graphical Multiple Correlation of Corrosion Data. O. B. Ellis. (*Corrosion*, 1953, **9**, June, 203–208). A graphical procedure may be used instead of a mathematical treatment for the analysis of corrosion data involving several variables. The graphical method is simpler to use and not limited to linear functions. The method is illustrated by a comparison of 20 low-alloy steels. The results are in close accord with a mathematical analysis of the same data.—J. F. S.

Electrochemical Behaviour of Metals as a Basis for the Study of Corrosion. R. Piontelli. (*Corrosion*, 1953. **9**, Apr., 115–122). Some general concepts in the study of the electrochemical behaviour of metals are introduced. The experimental determination of polarization curves is discussed on the basis of the results obtained working with model cells for which new arrangement is described. Some general rules are deduced concerning the electrochemical behaviour of metals and these are related to their corrosion and structure properties and passivity.—J. F. S.

The Protection of Iron and Steel by Metallic and Non-Metallic Coatings—II. J. C. Hudson and J. F. Stanners. (*J. Iron Steel Inst.*, 1953, **175**, Dec., 381–390). [This issue].

The Costs of Corrosion and of Its Control. W. H. J. Vernon. (*Proc. United Nations Sci. Conf. on the Conservation and Utilization of Resources*, Lake Success, 17 Aug.–6 Sept. 1949. **2**, *Mineral Resources*, 218–222). The costs of corrosion and its control are discussed in relation to the world shortage of metals. Large-scale reduction in the corrosivity of the main environments to which metals are exposed can be looked for only in atmospheric corrosion, of which by far the greatest amount is directly related to atmospheric pollution. Appreciably greater costs of initial treatment may be justified by reduced costs of maintenance and less overall cost.—J. C. B.

The Fight against Corrosion. (*Pact*, 1952, **6**, Dec., 470–472). The activities of CEBELCOR (Belgian Centre for the Study of Corrosion) are reviewed. This organization consists of technical committees dealing with particular topics such as electrodeposition, cathodic protection, etc.—A. G.

An Investigation of Fretting Corrosion. K. H. R. Wright. (*Inst. Mech. Eng., Preprint*, 1953, Feb. 20). Experiments are described in which two lapped carbon steel surfaces were loaded against each other, and subjected to slight oscillatory movement. Quantitative measurements were made of the fretting damage, by determining the weight of material removed, by using a sensitive progressive relapping technique combined with measurements of the damaged surface area. The degree of corrosion is correlated with number of oscillations, load, and atmospheric humidity—the humidity having a pronounced effect. Nickel plating is ineffective as an anti-fretting surface, unless it can be assumed that the plate has the additional effect of reducing the slip between the two surfaces. The use of lubricated phosphated surfaces is recommended for inhibiting fretting corrosion. Additional experiments have been carried out to establish the significance of the absorption and diffusivity of oxygen in surrounding liquid media. (18 references).—P. M. C.

Fretting Corrosion—What It Is, Its Cause and Possible Preventives. A. H. Allen. (*Metal Progress*, 1952, **62**, Dec., 71–76). Fretting corrosion is a surface deterioration occurring when closely fitting metal (or non-metal) surfaces move only minutely with respect to one another. Experiments are reported in which fretting was induced in specimens under microscopic observation. The evidence shows that fretting is caused by the loosening, due to the inherent adhesive forces, of finely divided virgin material. Molybdenum disulphide is a promising inhibitor.—B. G. B.

Intergranular Stress Corrosion Cracking of Unalloyed and Low-Alloy Steels and Its Prevention by Titanium or Titanium–Niobium Additions. E. Baerlecken and W. Hirsch. (*Stahl u. Eisen*, 1953, **74**, June 4, 785–789). The factors responsible for intergranular stress corrosion of unalloyed and low-alloy steels are reviewed. The stirrup test piece of J. A. Jones, immersed in boiling calcium ammonium nitrate solution has proved sufficiently accurate for assessing the resistance of steel to this form of attack. For steel tubes, a method has been developed in which rings are stressed by forcing them over mandrels of various diameters. Stress corrosion cracking can be prevented by addition of aluminium. Investigations on titanium and titanium–niobium steels led to the development of materials, resistant to caustic embrittlement, possessing advantages over aluminium steels. If the alloying elements are matched to the carbon content, the two types of steel can be heat-treated or welded without loss of resistance to caustic embrittlement.—J. P.

The Protection of Steel Structures in Salt Atmospheres. H. E. Bright. (*Australasian Eng.*, 1953, Jan. 7, 69–71). Experiments are described in which mild steel plates, cleaned and coated with various paints, zinc, and aluminium, were exposed to sea water. This accelerated test of coating life is approximately ten times as severe as the corrosion conditions existing at the Sydney Harbour Bridge, the paint coating of which has a life of about five years. For painting, sand blasting is the best method of cleaning the surface, red lead is a better primer than zinc chromate, and tung oil phenolic paint vehicle provides a more waterproof paint than alkyd vehicle. Aluminium was shown to be much the best protective coating of all the sprayed metals.—P. M. C.

Tests of the Protective Value of Metallic Coatings Under Sheltered Conditions (Marine Atmosphere). S. G. Clarke and W. N. Bradshaw. (*J. Appl. Chem.*, 1953, **3**, Apr., 147–154). Results of tests on the corrosion of a range of coatings on steel (electroplated zinc, cadmium, tin, lead, silver, lead–tin, tin–zinc and sprayed aluminium) are presented with special reference to parts stored in unsealed boxes in a marine environment. Metals anodic to steel, *e.g.*, zinc and cadmium, by preventing rusting at local perforations, are fully protective in layers thinner than those of cathodic metals, *e.g.*, tin or lead. Sulphurous pollution from industrial and domestic chimneys produces a strong sulphate component even at long distances from the source.—E. C. S.

The Effect of Impurities in the Metal on the Rate of Corrosion of Zinc and Galvanized Coatings in the Atmosphere. P. T. Gilbert. (*J. Appl. Chem.*, 1953, **3**, Apr., 174–181). Results of atmospheric exposure tests on zinc and galvanized coatings are summarized under: (1) Effect of additions to galvanizing bath on the corrosion-resistance of hot-dipped coatings, and (2) the behaviour of rolled zinc sheets of differing purity. In general, the effect of impurities in the metal was slight.—E. C. S.

Rust Solvents and Reaction Primers. A. Pollack. (*Chemiker Zeitung*, 1953, **77**, Mar. 20, 173–176). A survey of modern methods of preventing corrosion employed in Western Germany is made. Phosphoric acid processes, bonderizing, and reaction primers are mentioned, and reference is made to two German processes, the Edgerol process, in which rust is dissolved in acids and treated with potassium ferrocyanide, and the Dewozet process, in which a uniform layer of rust is produced on iron by pickling. According to the inventor this layer will, upon oxidation and drying at 200° C., form a good adhesive primer for lacquers. Neither of these processes appears to have got beyond the laboratory stage.—L. J. L.

Corrosion Prevention by Paints. J. E. O. Mayne. (*Bull. Inst. Met. Finish.*, 1953, **3**, Spring, 19–28). The mechanism of inhibition and the permeability of paint films are discussed. Being permeable to water and oxygen they cannot inhibit the cathodic reaction, but function because of their high electrolytic resistance. Paints can modify the anodic reaction provided the pigment is soluble in metal, or basic. Soap formation is beneficial since it renders the film less permeable to electrolytes.—L. J. L.

Rust Protection with Lead Cyanamide. H. Zirngibl. (*IVA*, 1953, **24**, 2, 48–53). [In German]. Lead cyanamide, a divalent rust inhibitor developed by I. G. Farbenindustrie, has a long-lasting alkaline passivating effect on H_2CO_3, SO_2 and H_2S, due to the facility with which it forms lead soaps in linseed oils. Having a low density of 6·2 g./cu. cm. it gives 50% greater coverage with only slightly increased oil content. Drying times range from 20 min. upwards. It can be mixed with all inert pigments and is especially effective when combined with hematite.—G. G. K.

The Attack of Iron-Saturated Zinc Melts on Iron. D. Horstmann. (*Stahl u. Eisen*, 1953, **73**, May 7, 659–665). Experiments have shown that the attack of molten zinc on iron at temperatures up to 490° and above 520° C. follows a parabolic time law, whilst between these temperatures, a linear time law is obeyed. The iron–zinc alloy layers increase parabolically with time below 490° and above 520° C., the Γ-layer determining the velocity of total attack. The higher iron losses found at temperatures between 480° and 490° C.

and between 520° and 530° C. are due to the fact that thinner iron–zinc alloy layers are formed as a result of inclusions in the ζ-layer. Between 495° and 515° C., the δ_1-layer floats into the zinc bath in fragments at the same rate as it forms on the iron surface. This explains the linear rate of attack at these temperatures.—J. P.

The Production of Stress Cracks in Steel by Molten Zinc. W. Rädeker. (*Stahl u. Eisen*, 1953, **73,** May 7, 654–658). The occurrence of intercrystalline cracking in stressed steel under the action of molten zinc has been investigated. Cracking was detected in samples subjected to alternating bending, continuous bending, or tensile stresses, while immersed in zinc. The molten metal acts very rapidly on the grain boundaries. In creep tests, brittle fracture occurred after a period depending on temperature, stress, and composition of steel. The importance of these findings in relation to the life of galvanizing kettles is discussed.—J. P.

The Corrosion of Scaling-Resistant Materials by V_2O_5, and the Effect on It of Various Alloying Elements. E. Fitzer and J. Schwab. (*Berg- hüttenmänn. Monatsh.*, 1953, **98,** Jan., 1–7). The recently observed accelerated corrosion of heat-resisting steels, occurring in combustion engines employing crude oils containing vanadium is examined. The accelerated attack is traced primarily to the formation of compounds between protective oxide layers and V_2O_5. A method of testing corrosion resistance under the simultaneous action of oxygen and V_2O_5, which yield reproducible results, is described. It is applied to iron–nickel base alloys containing different amounts of chromium, nickel, and silicon. The corrosion resistance of ordinary chromium steels can be considerably improved by providing them with a silicon-rich surface layer.

Corrosion Problems in Fire Extinguishers. L. Scheichl. (*Werkstoffe u. Korrosion*, 1953, **4,** Apr., 123–127). Practical examples are given of the failure of fire extinguishers through corrosion. The causes are classed under six heads : Faulty design, lack of proper protective treatment, use of materials with inadequate corrosion resistance, aggressiveness of the chemicals used, use of unsuitable chemicals, and neglect in service. A water fire-extinguisher made of sheet steel but fitted with a brass riser tube was perforated in a few months because of electrochemical corrosion made possible by the addition of an anti-freeze compound to the water.—J. C. H.

Limiting Corrosion in Tankers. L. A. Kisby. (*Dansk Tekn. Tidsskr.*, 1953, **77,** Jan., 16–17). [In Danish]. Unsuccessful attempts to prevent contacts between atmospheric water vapour and the sides of fuel tanks and so inhibit corrosion have led the Cargocaire Co. to adopt a method in which dehumidified air is passed into the tanks under 1½ lb./sq. in. pressure. Pressure is maintained at all times whether tanks are empty or full. Two banks of silica gel cylinders are employed, filter regeneration being automatically carried out hourly by means of a calorifier and fan.—G. G. K.

Corrosion in Water-Tube Boilers. S. D. Scorer. (*Elect. Times*, 1953, **123,** June, 1135–1137). The external corrosion of tubes in water-tube boilers is discussed. The regulations concerning the periodic removal of brickwork and inspection of the boiler have done much to reduce the risk of boiler explosion. External corrosion occurs as a result of wet soot and methods of reducing and removing soot deposits are discussed.—B. G. B.

Protection of Water Mains Against Corrosion. T. Sunnen. (*Rev. Tech. Luxembourg.*, 1953, **45,** Jan.–Mar., 23–29). The protection of steel and iron pipes for use as water mains is discussed. The influence which the nature of the soil has on the corrosion is stressed and the application of the bitumastic type of coating to the pipe before laying is described. Cathodic protection of pipelines, using magnesium anodes and current drainage, is considered.—B. G. B.

Structural Changes in Austenitic Stainless Steels. E. D. Bia. (*Bol. de la Facultad de Ing. Inst. de Ensayo de Materiales*, 1952, **4,** Oct.). [In Spanish]. The sensitivity of stainless steels and the application of the Strauss test for the detection of intergranular corrosion is explained. Methods of stabilization and their limitations are surveyed. Finally, the sigma phase and its identification are discussed and a metallographic examination of a stainless 16–18% Cr, 10–14% Ni, 2–3% Mo steel is reported.—R. S.

Simplified Low-Speed Rotor Techniques for Corrosion Testing. F. Wormwell. (*J. Appl. Chem.*, 1953, **3,** Apr., 164–169). Several rotor techniques are described. Corrosion is appraised by weight loss or depth of pitting on specimens in rod or sheet form. With single cylindrical specimens, electrode potentials were measured under conditions of rotation. The results help to explain the influence of cathodic and anodic polarization on the corrosion of mild steel in sea water.—E. C. S.

Improvement of the Stability of the Passive State of a Metal. N. D. Tomashov and G. P. Chernova. (*Doklady Akademii Nauk S.S.S.R.*, 1953, **89,** 1, 121–124). [In Russian]. The improved passivation in sulphuric acid of stainless steels alloyed with cathodic elements (Ag, Pt, Pd) is discussed. The electrochemical and corrosion characteristics of stainless steel 1X18H9 (18% Cr, 9% Ni) and its alloys containing : (1) 0·1% Pt ; (2) 0·1% Pd ; (3) 0·93% Pd ; and (4) 1·24% Cu were compared. The mechanism of improved passivation is deduced from experimental evidence.—V. G.

The Phenomena of Over-Passivation of Steel in Oxidizing Media. V. P. Batrakov and G. V. Akimov. (*Doklady Akademii Nauk S.S.S.R.*, 1953, **89,** 2, 321–323). [In Russian]. The resistance to corrosion of a carbon steel (·01% C) and a low-alloy chromium steel (0·3% C) in nitric acid of high concentration (50–100%) was investigated. The results are graphically presented. The phenomena of the increased velocity of corrosion in strong oxidizing agents at a concentration above the optimum was called over-passivation. The mechanism of corrosion under these conditions is discussed. Considerable changes in the corrosion velocity can take place when a small addition of an agent of high oxidizing power is made.—V.G.

Rôle Played by Nitrogen in the High Temperature Oxidation of Titanium in Air. V. I. Arkharov and G. P. Luchkin. (*Doklady Akademii Nauk S.S.S.R.*, 1952, **83,** 6, 837–839). The odixation of titanium and ferrotitanium alloys in air and oxygen was studied. On the basis of the kinetics of oxidation and an X-ray investigation of the oxide phase, a mechanism of oxidation was postulated.—V. G.

An Electron Micrograph Study of Oxide Films on Electropolished Surfaces of Iron. E. J. Caule and M. Cohen. (*Canad. J. Chem.*, 1953, **31,** Mar., 237–241). The electron microscope was used to determine the character of electropolished surfaces of iron. A film grows on the iron during the electropolishing and drying process, and this is disrupted by reduction with hydrogen. The effect of this film on the oxidation rate is discussed. Although the experiments were confined to one type of iron and one electropolishing bath, film formation nearly always accompanies electropolishing : when its absence has been noted, the fault lay with the means of detection.

ANALYSIS

Direct Determinations of Zinc and of Phosphorus in Steels with the Help of the Macq Electronique Apparatus. A. Hannick. (*Rev. Univ. Min.*, 1953, 9th Series, **9,** July, 436–441). The use of a direct reading spectrometer for the determination of some elements in zinc, and phosphorus and copper in steels, is described. The determination of phosphorus in steel containing copper is not straightforward, as the copper interferes. The apparatus has been used satisfactorily for the analysis of over 12,000 samples.—B. G. B.

Spectroscopic Determination of Oxygen in Steels. B. Rosen. (*Rev. Univ. Min.*, 1953, 9th Series, **9,** July, 445–454). A new apparatus is described for the determination of oxygen in steels. The sample is contained in a graphite crucible in an argon atmosphere and subjected to an electric discharge. The steel is melted and the oxygen combines with the graphite to form carbon monoxide. Spectroscopic measurements of the intensities of the carbon monoxide lines relative to those of argon enable the quantity of oxygen liberated from the steel to be determined with an accuracy of ±10% for oxygen contents varying from 0·001 to 0·03%. The possible application of the principle for the determination of other elements is discussed.—B. G. B.

Application of the Direct Spectroscopic Method for the Analysis of Steels and Irons in a Basic Bessemer Plant. V. Mathien. (*Rev. Univ. Min.*, 1953, 9th Series, **9,** July, 441–445). The use of a direct reading spectrometer of American construction (the Production Control Quantometer) for the routine analysis of open-hearth steels is discussed. The equipment is capable of analysing 13 elements, and phosphorus, manganese, and silicon can, for example, be determined in 5–6 min. Owing to the closeness in wavelength of

the spectral lines of phosphorus and copper, the concentration of phosphorus is determined by the difference in the intensities of this line and the pure copper line.—B. G. B.

Spectrographic Analysis of Steel During Refining and in the Control Laboratory. S. Michonsniky. (*Rev. Mét.*, 1953, **50,** May, 341–351). The organization of a laboratory with an intermittent arc spectrograph, capable of analysing 10,000 samples a month, is described. The three-ray method due to Scheibe is utilized and standardization is carried out with crucible steels. The analysis of finished products is outlined and rapid methods of melt control in which the electrode is obtained by sucking metal up a silica tube and special methods of developing, fixing and drying the photographic plate are employed.—A. G.

Research in Analytical Instrumentation. R. H. Müller. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 1–7). This account of the application of instrumentation to analytical research emphasizes the value of servo-mechanisms and includes a consideration of automatic weighing and descriptions of a photoelectric refractometer and an automatic titrator.—J. O. L.

The Value and Economic Importance of Chemical Analysis in Industry and Manufacture. L. H. Lampitt. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 8–16). Analysis in industry provides data for the translation of original research to the production level, affords a background for process development and represents a decisive factor in routine control. To be effective, it must be rapid and economical, conditions generally achieved by instrumentation, and its value for concluding national and international agreements must be soundly based on mutually acceptable fundamental principles.—J. O. L.

A Contemporary Assessment of the Place of Classical Methods in Chemical Analysis. C. J. van Nieuwenberg. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 17–21). Instrumentation has developed but not altered the application of many classical methods of chemical analysis and perhaps the best examples of new techniques are emission spectrography, mass spectrography and X-ray analysis. Of these, emission spectrography and X-ray analysis have limitations which make it unlikely that they can entirely replace classical methods, but there are indications that mass spectrography may in time provide all the information originally obtainable by chemical procedures.

Approaches Utilised in the Development of Spot Tests. P. W. West. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 55–61). Modification of conditions of reaction and a knowledge of the characteristics of spot-test reagents permit considerable extension of their application for analytical identification.—J. O. L.

A Fundamental Approach to the Establishment of *p*H Standards. R. G. Bates. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 97–104). The usefulness of *p*H measurements can be considerably increased by taking into account factors such as activity coefficients, by which means comparative data can be established.—J. O. L.

Determination of the Equivalence Point in Potentiometric Titrations, Part II. G. Gram. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 105–115). By correction for volume changes the $\Delta E/\Delta V$ curve can be transformed to two straight lines and the equivalence point of a titration is indicated by their point of intersection.

Square-Wave Polarography. G. C. Barker and I. L. Jenkins. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 129–140). Concentrations of reversibly reduced ions down to $2\times10^{-7}N$ can be polarographically determined by the application of square-wave voltages ; modifications permit certain ions to be determined down to $10^{-9}N$. Major amounts of ions interfering in ordinary polarography are without effect.—J. O. L.

The Colorimetry of Indicators. J. King. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 186–202). Measurement of the most desirable colour changes in indicators has shown that, although certain mixed indicators do not ideally satisfy theoretical requirements, their change points are sufficiently distinctive and close to the titrimetric neutral point for their use to be recommended.

Metals in Oils: Their Determination by Spectrographic Methods and the Errors Involved. A. J. Ham, J. Noar and J. G. Reynolds. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 210–217). After clarification of the oil and impregnation of graphite electrodes with it, normal spectrographic technique permits satisfactory spectrograms to be obtained. Concentrations may be calculated direct from density measurements without serious error, the deviation from chemical analysis being normally within 4–5%.

Some Factors Controlling the Selectivity of Organic Reagents. H. M. Irving and R. J. P. Williams. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 257–273). Sensitivity tests for the preliminary investigation of new reagents are discussed and correlations noted between the stability of metal complexes and (1) their intrinsic solubility, (2) the nature of the metal (3) the nature and acid dissociation constant of the reagent, and (4) the *p*H of precipitation or extraction. Examples are given for specific reagents.

Tungsten Steels: Rapid Method of Spectrographic Analysis. K. Dixon. (*Iron Steel*, 1953, **26,** May 14, 200–206). A spectrographic method, based on the flat surface sparking technique, for the rapid analysis of tool steels is outlined, covering the ranges 5–22% W, 0·1–20% Co, 2–6% Cr, 0·1–4% V, and 0·1–6% Mo. All types of tool steel except those with 3–5% V can be analysed from a single set of working curves. Data are included on the effect of available sparking area, sample size, and heat-treatment on the stability of these curves.—G. F.

The Photometric Determination of Copper in Unalloyed and Low-Alloy Steel with *o*-Tolidine. H. Blum. (*Arch. Eisenhüttenwesen*, 1953, **24,** May–June, 207–210). After solution of the sample in sulphuric-nitric acid, the iron is precipitated with ammonia and removed by filtration. A portion of the filtrate is neutralized with sulphuric acid, buffered with ammonium acetate and then treated with gelatine solution, potassium thiocyanate and *o*-tolidine and the extinction of the resulting blue-coloured solution is measured with a photometer. The method is suitable for steels containing up to 0·5% Cu and can be carried out in 20–25 min.—J. P.

Iodometric Determination of Copper and Iron. S. J. Quader and M. H. Khundkar. (*J. Indian Chem. Soc.*, 1953, **30,** May, 342–344). A new method for iodometric co-determination of copper and iron in a single aliquot sample is reported. This involves the determination of copper first by forming iron hexafluoride complex in acetic acid solution. After the titration of copper the iron complex is decomposed quantitatively with mineral acid and the iron iodometrically determined.—J. C. B.

Determination of Cerium in Steel. (*Handbuch für das Eisenhüttenlaboratorium*, 1941, **2,** 184–189). Methods of determining cerium in steel, recommended by the Chemists' Committee of the Verein Deutscher Eisenhüttenleute, are described.

A Note on Rapid Alkalimetric Estimation of Magnesium, Present Alone or in Presence of Calcium, Strontium, Barium, and in Sea Water. M. M. Tillu. (*J. Indian Chem. Soc.*, 1953, **30,** Jan., 79–80).

Identification of Molybdenum in Minerals and Alloys. F. Feigl and L. Baumfeld. (*Anais Assoc. Quimi Brasil*, 1951, **10,** 14–16). [In Portuguese].

Spectrographic Determination of Magnesium in Malleable Cast Iron by the Solution Method. M. Dvořák and J. Kuba. (*Slévárenství*, 1953, **1,** 3, 73–74). [In Czech].

Spectrochemical Determination of Lead in Ferrotitanium. A. Larsson. (*Jernkontorets Ann.*, 1953, **137,** 6, 191–193). [In Swedish]. A spectrochemical method for the determination of lead in ferrotitanium using solutions is described. The powdered alloy is dissolved in fluoric and nitric acid and a drop of the solution is evaporated in a carbon electrode. For excitation an interrupted D.C. arc is used. Lead in the range of 0·005–0·1% can be determined with an accuracy of about ±5% of the amount present.

Polarographic Determination of Lead in Lead Plating Solutions. R. Diaz. (*Plating*, 1953, **40,** Mar., 261–263). A portion of the plating solution is treated with gelatine solution, diluted and added to an equal volume of $2M$–KNO_3 solution. A polarogram is recorded between −0·50 and −1·00 V. *vs.* the internal mercury anode. The lead concentration is determined from the ratio of the wave height to those of standards solutions treated in the same way.—J. P.

Lamson Tube System: How Steel Samples Are Conveyed at the Works of the Steel Company of Wales, Limited. L. B.

Mayne. (*Brit. Steelmaker*, 1953, **19,** June, 389–391). At the Port Talbot, Margam, and Abbey works of the Steel Co. of Wales Ltd., the Lamson tube system is used for conveying samples and analytical reports between the melting shops and the metallurgical laboratories. This article describes the layout and operation of the system and discusses its advantages.—G. F.

The Use of the Eschka Method for the Determination of High Sulphur Contents. R. A. Mott and H. C. Wilkinson. (*J. Appl. Chem.*, 1953, **3.** May, 218–223). The incineration period for determining sulphur in coal can be reduced in a well-ventilated muffle to 1 hr. at 775–800° C. for a 1 g. sample with 4 g. of Eschka mixture. The same time is required for high sulphur contents with 0·1 g. samples. To obtain complete precipitation of the SO_4''-ion excess barium chloride must be added.—E. C. S.

The Rapid Determination of Calcium in Magnesite. H. Flaschka and F. Huditz. (*Radex Rundschau*, 1952, No. 4, Aug., 181–185). A new rapid and accurate method for the determination of calcium in magnesite is described. After removal of sesquioxides calcium is precipitated at boiling temperature with alkalinaphthal hydroxamate. The quantitative precipitate filters easily and little magnesium is co-precipitated. After wet combustion, the residue is alkalized and titrated with ethylenediamine tetra-acetic acid using murexide as indicator. The total time involved is about 3 hr. Results agree with those from double oxalate precipitation.—E. C.

Statistical Aspects of Analytical Determinations. W. J. Youden. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 318–322). The detection and correction of sources of error in analytical procedures is a major concern of analytical chemists. The efficiency of the search for the sources of analytical errors can be increased by scheduling the order of making the determination so that the determinations fall into rational groupings. Two new types of groupings are presented, which have features that are expected to make them more useful to investigators than those previously available.—J. O. L.

Statistical Design in the Study of Analytical Methods. G. E. P. Box. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 323–335). The uses of statistical design are discussed in investigations (*a*) to determine the sensitivity of an analytical method, and (*b*) to determine the conditions making some quantity (such as percentage recovery) a maximum.—J. O. L.

Instrumental Approaches to Paper Chromatography. Doris C. Müller. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 377–386). The theoretical aspects of paper chromatography can be studied with the aid of semi-automatic instruments. Recent instruments used by the author have been based on the square-law behaviour of the ascent or descent of liquid in a strip or sheet of paper. An improved optical scanner for examining chromatograms has proved successful in these studies ; for example, in delineating the shape of a band and evaluating R_F values more closely.

Quantitative Inorganic Paper Chromatrogaphy. A. Lacourt, G. Sommereyns, and G. Wantier. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 387–398). A study of the six influencing factors has led to a definition of conditions for obtaining individual chromatographic areas on paper. The separation of aluminium, iron, and titanium has been quantitatively checked, and the procedure has been successfully applied to steels and refractories.—J. O. L.

Application of Ion Exchange to Analytical Chemistry. E. R. Tompkins. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 414–426). Several theories have been proposed to explain the behaviour of solutes being selectively eluted from exchange columns. The plate theory, although limited in the range of conditions to which it applies, is the most useful one for predicting easily the degree of separation of solutes. Special devices for recording the concentration of various substances in the effluent are useful when a series of similar ions are being separated. In many instances the elution curves from these recorders can be analysed by application of the plate theory, and the quantity of each solute can be estimated even when they have not been completely separated.—J. O. L.

Inorganic Chromatography on Cellulose. F. H. Burstall and A. F. Williams. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 427–443). A new chromatographic method, based on cellulose as absorbent and ethyl methyl ketone containing hydrofluoric acid as solvent, is described for the quantitative separation of tantalum from niobium and for their determination in minerals, ores, and synthetic materials.—J. O. L.

Ageing of Crystalline Precipitates. I. M. Kolthoff. (*Proc. International Congress on Analytical Chemistry*, Oxford, Sept. 4–9, 1952, 444–455). The term " ageing " is used to denote all those irreversible structural changes that occur in a precipitate after it has been formed. The growth of larger particles at the expense of the smaller (" Ostwald ripening "), presumably owing to the greater solubility of the latter, is the classical example of ageing. Ageing is not entirely limited to physical processes ; hydrous oxides and hydroxides afford examples of chemical ageing through the mutual chemical interaction of primary particles.—J. O. L.

Spectrochemical Analysis of Magnesite. F. Kahler, H. Haas, and C. Fischer. (*Radex Rundschau*, 1952, No. 1, Feb., 33–45). The spectrochemical laboratory and equipment at the Radenthein magnesite works are described, together with the methods used for analysis of raw and sintered magnesite. Special sampling and excitation techniques are applied for quantitative determination of minor constituents (Si, Al, Fe, Ca, Mn) because of the irregular distribution of the latter.

Volumetric Determination of Calcium and Magnesium in Calcareous and Magnesian Materials. M. D. E. Jonckers. (*Chim. Analy.*, 1953, **35,** May, 101–108). Calcium and magnesium may be titrated with satisfactory accuracy against a solution of disodium ethylenediamine tetra-acetate using murexide and eriochrome black *T* as indicators. A simple method is given for the routine analysis of calcium and magnesium in fluxes, limestones, and dolomites used in metallurgy. The time taken is about 30% of that required for analysis by the oxalate and ammonium phosphate methods.

A New Microchemical Method for the Detection and Colorimetric Estimation of Ferric Ion. C. Ott. (*Chim. Analy.*, 1953, **35,** July, 149–152). With ferric ions the commercial reagent ' chrome-yellow O ' gives a yellow to brown colour which may be used for both qualitative and quantitative determination of Fe^{+++}. The only other elements that give colours with the reagent are palladium and uranium. The limit of sensitivity of the reagent corresponds to a dilution of 2×10^{-6}.—B. C. W.

Simple Tests for Identifying Some Nickel Alloys and Other Metals. (*Nickel Bull.*, 1953, **26,** Apr., 48–49). A simple series of tests for rapidly identifying the following alloys is described: Nimonic alloys, Inconel, 18/8 stainless steel, Monel, Ni-Resist, copper-nickel alloys, straight chromium stainless steel, ordinary steels, and nickel. Four tests are applied in the following order : Magnetic, reaction with nitric acid, copper deposit test with iron nail, and a supplementary check on Inconel and Nimonic alloys by using cupric chloride solution.

Photocolorimetric Titration in the Analysis of Alloy Steels. M. S. Gaukhman, B. E. Reznik, and G. M. Ganzburg. (*Zavodskaya Laboratoriya*, 1950, **16,** 9, 1045–1048). An accelerated method for determining manganese and chromium in a single weighed sample has been developed ; it employs photocolorimetric titration. The average error for manganese is 0·02% in the presence of 0·4–1·2% Mn ; with chromium the error is 0·22% in the presence of 15–30% Cr. Up to 20% nickel and up to 9% tungsten do not interfere. A determination takes 25 min. A method for vanadium requiring 35 min. has also been developed.—R. A. R.

X-Ray Fluoroscopy Analyses Alloys. R. M. Brissey and G. A. Chase. (*Machinist*, 1953, **97,** May, 30 886–887). The General Electric XRD–3S fluorescent X-ray spectrometer gives rapid results with an accuracy comparable with that obtained by the chemical analysis of high temperature alloys and stainless steels. The instrument is described.

Direct Analysis of Steels by the " Macq-Electronique " Apparatus Constructed by Radio-Synthèse. A. Hans. (*Rev. Univ. Min.*, 1953, 9th series, **9,** July 428–435). A new apparatus, built in Belgium, for the direct spectroscopic analysis of steels is described. The results of analyses carried out at a steelworks for the determination of silicon and manganese in open-hearth and electric steels are given and discussed. The quadratic errors of these direct spectroscopic

analyses are less than those for conventional chemical methods, and are 3% in the case of manganese and 4% in the case of silicon.—B. G. B.

HISTORICAL

Sir William Chandler Roberts-Austen, F.R.S. E. N. Simons. (*Brit. Steelmaker*, 1953, **19,** July, 422–425). The career of Sir William Chandler Roberts-Austen is outlined and his contributions to the study of metallurgy are enumerated.

Iron and Steel in Roman Britain. F. Evans. (*Brit. Steelmaker*, 1953, **19,** Aug., 468–471). The author discusses the production of iron, and even of steel, in Roman Britain, concentrated at a great military forge at Bath which drew raw materials from the Weald and from Wales.—G. F.

Campaign and Output of the Furnace at Rievaulx, in Yorkshire, in 1591–92. H. R. Schubert. (*J. Iron Steel Inst.*, 1953, **175,** Dec., 379–380). [This issue].

The Rise and Development of Sheffield Industry. G. P. Jones. (Sheffield Trades Historical Society : *Engineer*, 1953, **196,** July 17, 91–92). The author reviews briefly the history of Sheffield, tracing back the production, for instance, of knives over the last 600 years.—M. D. J. B.

ECONOMICS AND STATISTICS

The French Steel Industry. J. Bertin-Roulleau. (*Mét. Constr. Mécan.*, 1953, **85,** July, 579–581, 591). A short account of the French steel industry, which gives details of the production of steel in the various regions, is given. Production of iron in 1952 was 9·8 million tons and that of steel 10·9 million tons.—B. G. B.

The Effect of Mechanization upon the Iron and Steel Industry. S. F. Kasjanow. (*Mechanization of Complicated Large Scale Processes* (Moscow), 1951, No. 10, 12–15 ; *Met. u. Giesserei Techn.*, 1952, **2,** May, 152–155). A review is given of the progress of mechanization since 1945 in the iron and steel industry of the U.S.S.R. Figures are given for the savings in manpower, materials, and costs.—L. J. L.

Metals Economy—V: Substitution of Metals by Plastics: Recent Progress in Industry. J. M. J. Estevez. (*Iron Coal Trades Rev.*, 1953, **166,** Mar. 6, 551–554). The author discusses the possible substitution of metal components by plastics, and puts forward twenty examples of such substitutes which have already proved successful.—G. F.

Technical Improvements in the Use of Steel. (*Organisation for European Economic Co-operation*, Mar., 1953). The replies of different countries show that Europe has made great efforts in the past few years towards an increasingly rational use of steel and, on the basis of improvements in technique, towards economies in steel consumption.—J. C. B.

The Present State of Basic-Bessemer Steel Production. W. Küntscher. (*Met. u. Giesserei Techn.*, 1953, **3,** Jan. 2–9). The author believes that the proportion in total world steel production of basic-Bessemer steel is bound to increase, owing to a shortage of raw materials and an expanding production. Capital investment is less than for the basic open-hearth process.—L. J. L.

The Swedish Iron and Steel Industry Today. G. De Geer. (*Tekn. Tidskr.*, 1953, **83,** June 9, 485–486). [In Swedish]. Swedish annual output should exceed 2 million tons cast by 1955. Charcoal prices have increased to prohibitive levels, but it is hoped to counteract this by using sponge iron made by the Wiberg–Söderfors process, production of which will soon be 200,000 tons/year. New efforts are in hand to use pig iron from coke instead of charcoal. Swedish advantages from ores low in sulphur and phosphorus have been lessened by the advent of new electric refining methods and unless prices are reduced by increased productivity, future markets may be uncertain.—G. G. K.

The American Steel Industry. J. Bertin-Roulleau. (*Mét. Constr. Mécan.*, 1953, **85,** May, 407–409). Brief accounts of the production capacities of the steelmaking districts in the U.S.A. are given.—R. A. R.

Concerning Spanish Ferrous Metallurgy. (*Echo Mines*, 1953, Mar., 171–173). A production target of 1,600,000 tons of steel in 1956 is put forward to be achieved by means of a new works at Avilés, and by improving existing plant. Much capital is needed for this programme and output is also hindered by the shortage of scrap and good coking coal.—A. G.

Biscayan Industry in 1951. (*Bol. Min. e Indust.*, 1952, **31,** Dec., pp. 511–522). [In Spanish]. Useful data are presented on production, export and consumption of Biscayan ore, distribution of these ores from Spanish ports to various countries, output of pig iron, steel, rolled products, tinplate, and the value of production from the Altos Hornos de Vizcaya, Baracaldo y Sestao, Basconia, and Echevarria companies.

Capacity, Products, Future of the Canadian Steel Industry. R. D. Hindson. (*Eng. J.*, 1953, **36,** Apr., 390–394). The industry is surveyed in terms of raw materials, transportation, production, and demand. Expansion by the end of 1953 will bring a 235% capacity increase over pre-war years. The present programme will be sufficient to meet estimated requirements. Various factors combine to make it impossible for Canada to process all her own ore. A major development in the west coast industry is the planning of an electric smelting furnace.— K. E. J.

The Tinplate Industry in France and in the World. (*Usine Nouvelle*, 1953, Apr. 2, 21–22). Tinplate consumption which was 7,117,000 tons in 1950 is expected to be 9,150,000 tons in 1955. Apart from present scarcities of steel and tin, existing plant cannot cope with this demand. Production in America and Western Europe is discussed.—A. G.

MISCELLANEOUS

A Fast-Response True-Mass-Rate Flowmeter. Y. T. Li and S.-Y. Lee. (*Trans. Amer. Soc. Mech. Eng.*, 1953, **75,** July, 835–841).

The Large Scale Production of Oxygen. M. Leonard. (*Rev. Univ. Min.*, 1953, 9th series, **9,** Aug., 675–687). A survey of methods employed for the production of oxygen is made and the type of cycle used is explained with diagrams. The modern methods for the large scale preparation of oxygen for metallurgical uses are discussed and a description is given of a modern plant constructed by L'Oxygène Métallurgique. This plant is designed to produce oxygen of 95% purity at the rate of 130 tons/day.—B. G. B.

Recommended Care and Handling of Wire Rope. W. C. Richards. (*Iron Steel Eng.*, 1953, **30,** June, 120–122). The author discusses the precautions which should be taken to prevent damage to wire rope. Items dealt with are storage of rope, prevention of kinking, unreeling and uncoiling, inspection, and selecting a rope for a specific working load.

Cost Comparisons of Industrial Lighting. A Graphical Method of Comparing Different Types of Factory Illumination. J. Johnson. (*Elect. Times*, 1953, **124,** Aug. 13, 277–279).

Review of Iron and Steel Literature for 1952. V. S. Polansky. (*Blast Furn. Steel Plant*, 1953, **41,** June, 651–655 ; July, 782–784, 792). A list of books and pamphlets published during 1952, classified by subjects, is presented.

Frictional Resistance of Tubes. M. Macháček. (*Strojirenství*, 1953, **3,** 3, 200–201). [In Czech]. Formulæ for calculating the resistance of pipes to the passage of fluids in laminar and turbulent flow are compared with experimental results obtained in the 10^4–10^8 range of Reynold's numbers. The reasons for some divergencies between observed and calculated resistances are discussed.—P. F.

How the Production Engineer Can Be Helped by the Metallurgist. J. D. Jevons. (Inst. Production Engineers : *Sheet Metal Ind.*, 1953, **30,** Feb., 105–113, 134 ; Mar., 207–212). A descriptive review is presented under the following headings : Designing to facilitate production ; choice of manufacturing methods, processes and plant ; the danger of stamped identification marks ; stress-raisers—their nature and effect ; cracks—their origin and danger ; grinding cracks ; deduction of competitor's methods ; and the use of the metallurgical microscope.—P. M. C.

Work Study Application. H. J. Koch. (Inst. Production Engineers : *Engineer and Foundryman*, 1953, **17,** Apr., 93). The influence of work study is discussed with reference to productivity. Technical factors and the human problems associated with its introduction are considered.—A. D. H.

Trends in Technical Research in French Ferrous Metallurgy. M. H. Malcor. (*Echo Mines*, 1952, Feb., 93–95 ; Mar., 163–164 ; *Mét. Constr. Mécan.*, 1953, **85,** Mar., 159–165). Problems being studied include the coking of high volatile coals, treatment of fine ores, high top pressure operation, oxygen enrichment, purification of iron outside the blast-furnace, improvement of Bessemer steels, and the development of new steels.—A. G.

BOOK NOTICES

Interesting Achievements at the Works of Gilson á la Croyère. M. Stassin. (*Pact*, 1953, **7**, Feb., 57–59). Safety measures at this steelworks and foundry which are of general application are discussed. Machine layout and the provision of guards are studied by the maintenance office. Regulation of traffic, fire precautions in danger zones, and fume removal are dealt with.—A. G.

Problems of Ventilation and the Inhalation of Dust. M. Goenaga. (*Pact*, 1952, **6**, Oct., 347–355). After considering the psychological and physiological effects of dirty atmospheres, methods of purification are discussed. Noxious gases necessitate frequent changes of atmosphere or chemical treatment. Powders are treatable by extractor hoods, filters, wet and dry cyclones, or electrostatic precipitators.—A. G.

The Behaviour of Dusts Suspended in the Atmosphere. W. Muhlrad. (*Génie Civil*, 1953, **130**, June 1, 210–212 ; June 15, 229–233). After some statistics on the composition, particle size and amount of dust deposition in difficult areas the meteorological conditions affecting the dispersion of dusts are discussed, including temperature inversion. The technical aspect of dust emission and a study of the percentage dust deposited as a function of distance from chimney for different particle sizes, chimney heights, and thermal gradients are described.—A. G.

BOOK NOTICES

BADER, O., and D. GODOT. "*Les Fontes Spéciales, leur Elaboration, leurs Emplois.*" Préface de L. Quevron. La. 8vo, pp. 296. Illustrated. Paris, 1953 : Editions Eyrolles. (Price 1820 fr.)

This is essentially an account of the influence of composition on the structure and properties of cast irons. After a brief and simplified account of the microstructure, the solidification of cast iron and the influence of the normally occurring elements such as carbon, silicon, sulphur, manganese and phosphorus, the authors devote separate chapters to the various groups of alloyed cast irons. Nodular cast irons and malleable irons are also dealt with. There are sections on heat-treatment, melting furnaces, and defects in iron castings.

The material is presented in a simple, logical style which could be easily followed by foundry technologists. The authors have used few diagrams to illustrate the subject. Sixty micrographs are given at the end of the book, but these are of a very low standard.

Whilst the book is obviously intended for the practical man and is accordingly concerned for the most part with clearly established facts and processes practicable in the iron foundry, there are occasions when the authors insert information which is interesting but likely to mislead the practical founder. One learns, for instance, that nodular graphite is produced by beryllium, strontium, bismuth and barium, and in fact the influence of beryllium is considered of sufficient importance to warrant a micrograph to illustrate the structure produced. The practical man is left to decide whether practicable processes using these additions exist, and, if so, why they have not been widely applied.

In the section on spheroidal graphite irons, one learns of a simple process involving the addition of sulphur or selenium or tellurium, which may not give a perfect structure in the as-cast state when using grey irons, but which on casting white and annealing gives perfect spheroidal graphite. In this context, the authors omit to point out that much whiteheart malleable iron has been made with high sulphur contents, giving spheroidal graphite. The impression is created that this is a workable process which could presumably be applied to heavy-section castings in the same manner as the magnesium process. One can imagine how such statements could mislead.

The book occasionally refers to procedures and techniques which are perhaps less well-known in the English technical literature. A technique to reduce the coefficient of friction of components, involving heating in a salt bath containing compounds of sulphur, is described, but, returning to what must be the authors' favourite subject, it is pointed out that nodular irons treated with sulphur also have these remarkable properties. No evidence is produced to substantiate this.

At various points throughout the book the authors refer to oxygen in cast iron and claim that it has powerful effects. They repeat in various ways the theories of 20 years ago about oxide and silicate inclusions, and heredity of pig irons. No evidence is produced to support these beliefs, which are becoming increasingly in question.

When dealing with clearly established facts and common practices, the book gives a simple and useful account. Its arrangement is commendable and clear, but this does not compensate for the lack of an index.

The bibliography contains 75 references. It is difficult to believe that these represent those contributions from which the most authoritative information could be obtained.

H. MORROGH

BRITISH ELECTRICAL DEVELOPMENT ASSOCIATION. "*Electric Resistance Heating.*" (Electricity and Productivity Series No. 5). 8vo, pp. xvi + 182. Illustrated. London [1953]: The Association. (Price 9*s*.)

Throughout industry the application of heating in greater or less quantity is essential to various processes and this book describes the advantages of applying heat electrically.

In the opening chapter the case for electrical heating is succinctly summarized, the principal features being cleanliness, safety, ease of control, efficiency, convenience, and adaptability. The least self-apparent of these virtues is doubtless efficiency, since the whole complex of electrical generation and distribution is inserted between the source of heat, the fuel and the object to be heated. The point is made that conversion from electrical energy to heat is 100% efficient, whereas in the case of fuel, particularly with the smaller appliances, the conversion efficiency may be less than 50%. Electrical methods therefore score heavily where the heating element can be placed close to or inside the object to be heated.

The methods of controlling electrical energy and converting it into heat are dealt with, and the various types of elements available and their suitability for various applications are discussed. The adaptability of electrical heating is adequately demonstrated in later chapters, where it is shown that other sources of heat can be replaced by electric heaters of the immersion type or by strip heater elements that can be clamped on to the outside of a vessel.

The book describes numerous processes where electrical heating has been extensively used, the range extending from a 60-W. soldering iron to a 1000-kW. annealing furnace. The processes are well illustrated with line sketches and numerous photographs, and cover applications as diverse as infra-red heating, metal pots, platens and rollers, liquids, and steam raising, in addition to ovens and furnaces.

Useful tables of the heating properties of various materials are included, and two simple examples are worked out for calculating the electrical loading for certain processes.

The information is presented so as to be of interest to the non-technical reader and the general aim is to show what can be achieved by electrical heating. The book should therefore be a useful guide to anyone who has an industrial heating problem.—D. F. NETTELL

COTTRELL, A. H. "*Dislocations and Plastic Flow in Crystals.*" (International Series of Monographs on Physics.) 8vo, pp. ix + 223. Illustrated. Oxford, 1953 : Clarendon Press. (Price 25*s*.)

The pace and the relatively short duration of the development of dislocation theory have resulted in a situation in which a large number of scientific papers exist on the subject with only particular facets presented in text-books. The need for an exposition of the state of the subject to date is obvious, but the diversity of interest makes it difficult to design a presentation which will adequately cover the several needs of those who are actively interested either in the subject as a whole or in particular aspects of it. Further, the unestablished state of much of the theory poses a difficult problem in selection and presentation.

Professor Cottrell divides his book into five main sections. The first, "The Interpretation of Slip in Crystals," discusses the experimental evidence that plastic deformation occurs by means of slip, shows how slip may be accounted for by the movement of dislocations, and examines some general features of them. The second section, "Elastic Properties of Crystals," deals with the internal stresses in dislocated crystals. A dislocated crystal is considered as an elastic continuum containing singularities. The forces between various types of dislocations and free surfaces, etc., are discussed. Section III, "Dislocations in Crystals," examines the effect of the periodic structure of a crystal on the movement of dislocations. A discussion of specific dislocated lattices is given, and the rôle of dislocation theory in the theory of crystal growth and the structure and stability of crystal boundaries is considered. The fourth section, "Theories of the Yield Strength," commences with a discussion of the sources of, and obstacles to, slip in a crystal. An examination of slip in polycrystals follows, together with a treatment of alloy hardening. The part played by solute atoms in modifying the type of dislocation movement occurring in pure substances and thus producing the special features associated with alloys is considered. The final section is concerned with "Work-Hardening, Annealing, and Creep." This part of the subject is still in a very fluid state, and the author briefly discusses those topics which seem to be important under the general heading.

It is clear from this brief summary of the contents that the range covered is immense. Nevertheless, the treatment of each topic, though of necessity brief, is commendably adequate. For those who wish to pursue any particular topic further, the book is liberally supplied with references to the literature. Having regard to the main interests of some of the readers for whom the book is intended, the author has adopted the admirable expedient of making his intentions quite clear before embarking on any mathematics, and also the desirable practice of enumerating involved requirements or steps in arguments, which combine to make the book very easy to follow.

Professor Cottrell is to be congratulated on doing so competently a job which so obviously required to be done.

J. F. W. Bishop

Feldmann, Paul. "*Handbuch des Schleifens.*" 8vo, pp. 160. Illustrated. Essen, 1953 : Verlag W. Girardet. (Price DM 14·80).

This handbook attempts to supply an overall picture of grinding methods and materials available for grinding ; the emphasis, however, is on machine-shop grinding. It is written specifically for engineering students, apprentices and skilled tradesmen, but it will no doubt be of interest to metallurgists and others whose work necessitates some knowledge of grinding processes. Explanations are presented in simple language assisted by a liberal supply of diagrams and photographs of a high standard. Very effective use is made of the "Right Way—Wrong Way" type of diagram.

After a short preliminary chapter defining grinding and wheel structure, the author enumerates the composition and properties of natural and synthetic abrasives with outlines of their preparation and manufacture and the sources of raw materials. The effect of both conventional and modern bonds on texture and wheel hardness with methods of testing this hardness are dealt with, followed by the fundamentals of wheel-making, methods of storage, balance and dressing. Reference is made to the interpretation of makers' wheel codes, but more comprehensive tables of these systems would have been welcome.

The most detailed section, on machine-shop grinding practice, consists of two chapters. One describes tool grinding and covers most types of milling cutters, reamers, drills, lathe and carbide tools, but not the preparation of hand edge tools such as cutlery and wood-working tools. The shape and function of each tool are explained. Recommended cutting angles and rakes are tabulated for various metals and the set-up for maintaining these contours by grinding is illustrated. The detailed attention paid to the grinding, lapping and honing techniques for carbide tools is specially acceptable in view of their rapidly expanding usage.

In the chapter on machine grinding, internal, external, centreless, and surface grinding processes are described and accompanied by tables and graphs of wheel selection, speeds, and feeds, followed by a section of gauge methods. Arrangements for crank, piston, thread, and gear grinding are treated in a similar manner. Honing, polishing, slitting and, casting-fettling are only briefly mentioned, although the last of these is a major application of grinding; this, however, is an omission common to much larger volumes on grinding. The final chapter contains notes on personal safety precautions, types of steel compositions, and the identification of steels by their grinding sparks ; here, drawings of spark trails would have been more useful than verbal description.

For the qualified engineer or grinding specialist this book is elementary, but it successfully achieves its goal in supplying a bird's-eye view for trainees.—E. A. Oldfield

The Institution of Metallurgists. "*The Joining of Metals.*" Lectures delivered at the Institution's Refresher Course 1951. 8vo, pp. 174. Illustrated. London, 1952 : The Institution. (Price 14*s.*)

While one cannot say that the six papers contained in this book constitute any considerable contribution to knowledge, each paper surveys a particular aspect of the problem of joining metals.

The first paper, by Professor O'Neill, deals with the metallurgical principles in a wide manner, classifies the processes and gives the historical background. Marshall presents an adequate summary of the causes of gas porosity and hot-cracking in non-ferrous metals, on which a considerable amount of research work has been carried out in the last decade.

In dealing with the welding of constructional steels Reeve restricts the field to metallic arc welding, and discusses the various types of coated electrodes and the constitution and hot-cracking of the resulting weld metal. A good summary of the results of modern work on the hard-zone cracking of high-tensile steels is also given.

In a survey of the problems in welding chromium-nickel austenitic steels, the usual topics of weld decay, sigma formation and knife-edge corrosion are discussed, but Keating also adds some extra data from his wide experience in this field.

The last two papers deal with soldering and weldability tests, and in the latter Ball includes brief details of the latest work carried out at the British Welding Research Association.

There have been wide extensions of the use of welding in recent years and this book serves a useful purpose in presenting the metallurgical problems which arise ; it should find a place on the bookshelves of both metallurgists and engineers. Some critism might be made, however, of the quality of the half-tone pictures due to the type of paper used.—E. C. Rollason

Thews, Edmund R. "*Metallurgie, Technologie und Anwendung der Weichlote.*" 8vo, pp. 237. Illustrated. Berlin, Grunewald, 1953 : Metall-Verlag. (Price DM 9·60).

It is the professed aim of this book to collate the metallurgical literature on solders in a readily accessible form. A very large number of references have been consulted, but the bulk of the material was collected in the 35 years before the war ; the post-war material seems to be represented principally by the tables of Standard Specifications for the various metals and alloys. It is useful to have these and the tables of the physical properties of various solders and fusible alloys in a single volume. The section on the refining of solder metals and the compounding of solders will interest many and should be useful.

Nothing is said about creep in soldered joints nor as to possible embrittlement. Methods of evaluating the spreading of solders and the action of fluxes are not discussed, although there is a very long discussion on spreading so far as it was appreciated before the war.

The book provides plenty of alternative formulæ for solders and methods of soldering, but does not succeed in giving much guidance on their relative merits. There is no evidence of any desire to compress the information, and the discussion on fluxes, for example, could be greatly shortened with advantage to the readers, but as most of them will use the book as a reference manual that is of minor importance.—W. R. Lewis

AMERICAN SOCIETY FOR METALS. "*Behaviour of Metals at Low Temperatures.*" A Series of Three Educational Lectures on Behaviour of Metals at Low Temperatures presented to Members of the A.S.M. during the Thirty-Fourth National Metal Congress and Exposition, Philadelphia, October 20–24, 1952. 8vo, pp. [iv +] 112. Illustrated. Cleveland, Ohio, 1953 : The Society. (Price $3)

AMERICAN SOCIETY FOR METALS. "*Gases in Metals.*" A Series of Four Educational Lectures on Gases in Metals presented to Members of the A.S.M. during the Thirty-Fourth National Metal Congress and Exposition, Philadelphia, October 20–24, 1952. 8vo, pp. [iv +] 204. Illustrated. Cleveland, Ohio, 1953 : The Society. (Price $3)

AMERICAN SOCIETY FOR METALS. "*Modern Research Techniques in Physical Metallurgy.*" A Seminar held during the Thirty-Fourth National Metal Congress and Exposition, Philadelphia, October 18–24, 1952. 8vo, pp. [viii +] 335. Illustrated. Cleveland, Ohio, 1953 : The Society. (Price $5)

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Symposium on Continuous Analysis of Industrial Water and Industrial Waste Water.*" Presented at the Fifty-Fifth Annual Meeting of the American Society for Testing Materials, New York, N.Y., June 24, 1952. (A.S.T.M. Special Technical Publication No. 130). 8vo, pp. [v +] 54. Illustrated. Philadelphia, Pa., 1953 : The Society. (Price $1·50)

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Symposium on Strength and Ductility of Metals at Elevated Temperatures, with Particular Reference to Effects of Notches and Metallurgical Changes.*" Presented at the Fifty-fifth Annual Meeting, American Society for Testing Materials, New York, N.Y., June 23, 1952. (A.S.T.M. Special Technical Publication No. 128). 8vo, pp. [iv +] 249. Illustrated. Philadelphia, Pa., 1953 : The Society.

"*Die Amerikanische Industrie feuerfester Stoffe.*" Beobachtungen einer deutschen Studiengruppe in U.S.A., von Hubert Frank, Kurt Giesen, Gottfried Hendrickse, Kurt Laudien, Edward Stephan und Richard Zaeske. (Rationalisierungs-Kuratorium der Deutschen Wirtschaft. R.K.W.–Auslandsdienst, H.18). 8vo, pp. 90. Illustrated. München, 1953 : Carl Hanser Verlag.

ANGLO–AMERICAN COUNCIL ON PRODUCTIVITY. "*The British Pressed-Metal Industry.*" Report of a Productivity Team from the United States of America which visited the United Kingdom in 1951. La. 8vo, pp. viii + 36. Illustrated. London, 1953 : British Productivity Council. (Price 3*s.*)

ASSOCIATION OF IRON AND STEEL ENGINEERS. "*Tube Mill Practice.*" A Collection of Articles from the *Iron and Steel Engineer* on Various Phases of Tube Making. La. 4to, pp. [vi +] 194. Illustrated. Pittsburgh, Pa., 1953 : The Association. (Price 33*s.*)

AUSTIN, W. W., jun., and EDGAR S. GRAMLING. "*The Behaviour of Zirconium and Titanium in Steels, with Particular Emphasis on the Conservation of Manganese.*" A final report to the American Iron and Steel Institute. (American Iron and Steel Institute, Contributions to the Metallurgy of Steel, No. 41). 4to, pp. 40. Illustrated. New York, 1952 : The Institute.

BRITISH STANDARDS INSTITUTION. B.S. 1121 : Part 2 : 1953. "*Methods for the Analysis of Iron and Steel.*" Part 2. "*Nickel in Permanent Magnet Alloys.*" 8vo, pp. 8. London, 1953 : The Institution. (Price 2*s.*)

BRITISH STANDARDS INSTITUTION. B.S.1121 : Part 4 : 1953. "*Methods for the Analysis of Iron and Steel.*" Part 4. "*Aluminium in Permanent Magnet Alloys.*" 8vo, pp. 10. Illustrated. London, 1953 : The Institution. (Price 2*s.* 6*d.*)

BRITISH STANDARDS INSTITUTION. B.S. 1121 : Part 5 : 1953. "*Methods for the Analysis of Iron and Steel.*" Part 5. "*Copper in Permanent Magnet Alloys.*" 8vo, pp. 7. London, 1953 : The Institution. (Price 2*s.*)

BRITISH STANDARDS INSTITUTION. B.S. 1121 : Part 29 : 1953. "*Methods for the Analysis of Iron and Steel.*" Part 29. "*Sulphur in Basic Steelmaking Slags (Gravimetric Method).*" 8vo, pp. 6. London, 1953 : The Institution. (Price 2*s.*)

DUBROW, N. F. "*Die Blockstruktur bei unberuhigtem Stahl.*" Übers. aus d. Russ.) 8vo, pp. 68. Illustrated. Leipzig, 1952 : Fachbuchverlag. (Price DM 1·85)

EGOROV, K. A. "*The Fundamentals of the Mechanisation of Loading and Unloading Operations in Metallurgy.*" [In Russian.] Second, revised and enlarged, edition. 8vo, pp. 430. Illustrated. Moscow, 1952 : Metallurgizdat.

GAYDON, A. G., and H. G. WOLFHARD. "*Flames, their Structure, Radiation and Temperature.*" Pp. xi + 340. Illustrated. London, 1953 : Chapman and Hall, Ltd. (Price 35*s.*)

HERBERS, H. "*Härten und Vergüten des Stahles.*" 6. Aufl. (Werkstattbücher, Heft 7.) 8vo, pp. 68. Illustrated. Berlin, Göttingen, Heidelberg, 1953 : Springer-Verlag. (Price DM 3·60)

"100 *Jahre Stahlformguss.*" [Hrsg.] Gussstahlwerk Bochumer Verein A.G. 4to, pp. 52. Illustrated. Bochum, [1953] : The Company.

KIEFFER, R., and P. SCHWARZKOPF. "*Hartstoffe und Hartmetalle.*" Unter Mitarbeit von F. Benesovsky und W. Leszynski. 8vo, pp. xvi + 717. Illustrated. Wien, 1953 : Springer-Verlag. (Price 136*s.*)

KNIPP, ERWIN. "*Fehlererscheinungen an Gussstücken, Ursachen und Vermeidung.*" 8vo, pp. 275. Illustrated. Düsseldorf, 1953 : Giesserei-Verlag G.m.b.H. (Price DM 26.–)

KRASAVTSEV, N. I., and M. YA. OSTROUKHOV. "*Modern Blast-Furnace Practice for the Specialist.*" [In Russian.] 8vo, pp. 544. Illustrated. Moscow, 1949 : Metallurgizdat.

KULIBIN, V. A. "*The Preparation of Ores for Smelting.*" [In Russian.] 8vo, pp. 544. Illustrated. Moscow, 1952 : Metallurgizdat.

LANEUVILLE, JEAN. "*Sintering and Melting Points of Iron Ores from New Quebec.*" (Canada Department of Mines, Laboratories Branch, P.R. No. 265). 4to, pp. 11. Quebec, 1952 : Canada Department of Mines.

LANEUVILLE, JEAN. "*Porosity and Adsorptivity in Iron Ores from New Quebec Compared with Standard Ores.*" (Canada Department of Mines, Laboratories Branch, P.R. No. 277). 4to, pp. 22. Quebec, 1953 : Canada Department of Mines.

MOROSOW, Ss. M., and A. A. PLECHANOWA. "*Strukturfehler in Kesselblechen.*" (Übers. aus d. Russ. Metallkundliche Berichte, Bd. 54). 8vo, pp. 46. Illustrated. Berlin 1952 : Verlag Technik. (Price DM 5.–)

ODING, I. A., M. M. SAVERIN, S. I. JAZKEWITSCH, S. I. MATWEJEW, and T. I. WOLKOWA. "*Neue Verfahren zur Prüfung der Metalle auf Kriechfestigkeit und Erholung.*" (Übers. aus d. Russ. Wissenschaftliche Berichte, Band 33). 8vo, pp. 74. Illustrated. Berlin, 1952 : Verlag Technik. (Price DM 4.–)

OHIO RIVER VALLEY WATER AND SANITARY COMMISSION. "*Methods for Treating Metal-Finishing Wastes.*" Pp. 72. Cincinatti, Ohio, 1953 : The Commission (Price $2)

OKOROKOV, N. V. "*Electric Melting Furnaces in Ferrous Metallurgy.*" [In Russian]. Third, revised, edition. 8vo, pp. 564. Illustrated. Moscow, 1950 : Metallurgizdat.

PARADINE, C. G., and B. H. P. RIVETT. "*Statistics for Technologists.*" 8vo, pp. vii + 288. Illustrated. London, 1953 : English Universities Press, Ltd. (Price 25*s.*)

WYCKOFF, RALPH W. G. "*Crystal Structures. Volume III.*" La. 4to, loose-leaf. Illustrated. New York, 1953 : Interscience Publishers, Inc. ; London : Interscience Publishers, Ltd. (Price 116*s.*)

ZINC DEVELOPMENT ASSOCIATION. "*Second International Conference on Hot Dip Galvanizing Held at Düsseldorf, 30th June–4th July,* 1952." An Account of the Proceedings at the Conference with Revised Texts of the Papers Presented and of the Discussions on them. La. 8vo, pp. x + 238. Illustrated. Oxford, 1953: The Association. (Price 37*s.* 6*d.*)